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A

TREATISE

ON THE

ORIGIN, PROGRESSIVE IMPROVEMENT

AND

PRESENT STATE

OF THE

MANUFACTURE

OF

PORCELAIN AND GLASS.

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LIST OF WOOD ENGRAVINGS.

PORCELAIN.

GLASS.

"The arts may be said to imitate nature, or to help, or to overcome and advance nature: nor are they therefore to be esteemed less noble because more practicable, since our best and most divine knowledge is intended for action; and those may justly be counted barren studies which do not conduce to practice as their proper end."

Bishop Wilkins.

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MANUFACTURE
OF
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CHAPTER I.

HISTORICAL NOTICES OF THE MANUFACTURE.

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The formation of earthen vessels capable of containing fluid substances is an art of the very highest antiquity. In the rudest stages of society, the want of such vessels would call forth the inventive powers of mankind; and, probably, the hard shells of some vegetable productions, such as gourds and the larger descriptions of nuts, would be first adapted to the purpose. The pliant and infrangible nature of the skins of animals taken in the chase would, at a very early period, point them out as convenient recipients for fluids; but the preparation of these, as well as the fashioning and hollowing of wooden bowls, supposes a previous knowledge of some manual arts, and implies the possession of tools. After even these had been attained, and supposing that the existence of fire, and its use in preparing food, had become known, vessels formed of wood, or of the hides of animals, would be of little use in rendering that knowledge available. Some savage tribes thus circumstanced, have, indeed, made wooden bowls subservient to this purpose, by throwing into the fluids which

they contain, stones previously heated in the fire. This manner of boiling water, and of cooking provisions, is, however, at best, but an inconvenient process, and would be immediately abandoned upon the discovery that certain earthern substances were endowed sufficiently with the quality of resisting the action of fire.

It must continue matter of doubt, whether the fashioning and hardening of clay was practised first by the brickmaker or by the potter. We know that bricks, thoroughly burned, were used at the building of the tower of Babel, 2200 years before the commencement of the Christian era, and 600 years prior to the carrying away into captivity of the Israelites. That the use of bricks, for the purposes of building, must have become exceedingly common at this last-mentioned period, is evident, from the great numbers of the captive Jews who were compelled by their Egyptian task-masters to prosecute the manufacture. It appears that the bricks then made were not artificially burned; the chopped straw which entered into their composition, and which served to hold the mass together, would, in such case, have been destroyed. Specimens of very ancient Egyptian bricks, which have been brought to this country, confirm the supposition that the heat of the sun was alone employed in baking them.

Many centuries later, the Romans conducted the manufacture of bricks with a great degree of perfection. A comparison of very ancient Roman ruins, with buildings of modern elevation, will show at once how superior are the bricks employed in the former, both as regards solidity and beauty. Specimens of the potter's art, if even any such existed at an equally early period, could not be expected to continue in being for so many ages; if, indeed, they had withstood the destroying hand of time, and descended to the present day, they would not bring with them any direct testimony of their date of production, and could throw little or no light upon the question of priority. It is certain, however, that, in very remote ages, the potter's art had attained to a considerable degree of usefulness, since the earliest authentic records allude to the potter's wheel as to an implement of then high antiquity.

The same wants would arise in different portions of the globe; and in all cases, where similar means for their gratification presented themselves, it is not surprising that these means should be equally embraced by all. Accordingly, it has been found, in newly-discovered countries, and among people comparatively rude and unacquainted with most of the arts which conduce to human convenience, that the use of earthen vessels has been enjoyed for ages before the existence

of the people was even surmised. Among other proofs of this fact, it may be mentioned, that vases have been found among the aboriginal Indians on the Mosquito shore, which, even by those people, were preserved as memorials of antiquity. There is no reason to doubt that these vessels were the manufacture of the country in which they were found, as the remains of ancient potteries have been discovered at a considerable distance up the Black River on that coast.

There would be little advantage in entering upon an investigation to determine the precise degree of antiquity of the potter's art, if even there existed any sufficient guides to direct us in the inquiry. It will be more profitable at once to forego all fanciful speculations, and to commence the relation of a few facts, and such only as bear the stamp of authenticity. The detail of these need not occupy much time or space, which may be more advantageously devoted to descriptions of the art as it exists in the present day, than to the building up of theories, the truth of which can never be demonstrated.

We learn, on the authority of Vitruvius, who wrote in the Augustan age, that the Romans then made their water-pipes of potter's clay. This people, who introduced a knowledge of the useful arts practised by themselves wherever their conquests were extended, established potteries in England, where, among other articles, similar water-pipes were made. Some of these, about a century ago, were dug up in Hyde Park. They were found to be two inches in thickness, and were firmly jointed together with common mortar mixed with oil.

It has been asserted that the ancient Britons were in the practice of making pottery before the invasion of this country by the Romans; and in support of this belief is brought the fact, that urns of earthenware have been taken from barrows in different parts of the kingdom. On the other hand, the concurring testimony of various writers gives reason for supposing that our ancestors were in those days supplied with such articles by the Venetians. Vestiges of considerable Roman potteries are discernible in many parts of the island, and particularly in Staffordshire, on the site of the great potteries which have so long been carried on in that county. In sinking pits for various purposes, remains of Roman potteries have occasionally been discovered there at a considerable depth below the surface.

Governor Pownall relates, that in his time (1778) the men employed in fishing at the back of the Margate Sands, in the Queen's Channel, frequently drew up in their nets some coarse and rudely-formed earthen vessels, and that it was common to find such pans in the cottages of these fishermen.

It was for some time believed, that a Roman trading vessel, freighted with pottery, had been wrecked here; but on more particularly examining the spot, called by the fishermen Pudding-pan Sand, some Roman bricks were also discovered, cemented together, so as to prove that they had formed part of some building. Further researches showed that, in Ptolemy's second book of Geography, an island was designated as existing in the immediate vicinity. Such pans as were recovered in a sound state were of coarse materials and rude workmanship—many having very neatly impressed upon them the name of Attilianus; but fragments of a finer and more fragile description of pottery were likewise brought to the surface; and little doubt remains that, during the time of the Roman ascendency in England, a pottery was established here upon an island which has long since disappeared, and that the person whose name has been thus singularly preserved was engaged in its management.

The high antiquity of the art in China, and the proficiency which had been acquired in its pursuit, several centuries before the produce of their manufactories found its way to Europe, will be shown in a future chapter. Porcelain of superior quality was likewise made in Japan at an equally early period; and we learn from Propertius, that at a very remote date, the art was commonly practised in Persia, the vessels manufactured there joining to all the excellencies possessed by the porcelain of China, the quality of resisting the action of fire to a degree which fitted them for being used in the preparation of food.

Most authors who have noticed in any way the state of commerce among the ancients, have referred to the *Vasa Murrhina* particularly described by Pliny,* and mentioned by various Greek and Roman authors. The general opinion was long in favor of these vases having been the true porcelain of China. This opinion has, however, been examined with considerable industry and erudition by M. l'abbé le Bland and M. Larcher, in two dissertations,† whereby it is rendered evident that the Vasa Murrhina were formed out of a transparent stone dug from the earth in some of the eastern provinces of Asia.‡ There is abundant evidence to show that Oriental porcelain was not uncommon in Europe during the first century. The pieces of this manufacture which, according to Pliny, were first seen in Rome, were brought there from Pontus in Asia, by the army of Pompey, 64 years before Christ.

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* Nat. Hist. lib. xxvii. † Mém. de Litterat. tome xliii.

‡ Robertson's Disquis. concerning India, second edit. p. 287.

Little figures covered with a fine deep-blue glaze, which are found deposited with Egyptian mummies, cause it to appear that porcelain was made in Egypt in very ancient times. It is a curious fact, that the coloring matter wherewith these figures are ornamented, and which has been subjected to various chemical tests, affords every indication of its being oxide of cobalt, the identical substance employed for the same purpose by the European porcelain manufacturers of our day, but the use of which was unknown to us until a comparatively recent period. The ore of cobalt was formerly thrown aside by the miners of Saxony as useless, or was employed only in mending roads.*

The Portuguese traders were the means of introducing the fine earthenwares of China into more general use in Europe; and the name assigned to the fabric, as distinguishing it from the coarser descriptions of pottery of domestic manufacture, was most probably given by them—*porcellana* signifying, in the Portuguese language, a cup. It has been attempted to prove a different origin for the name—attributing this to the resemblance which the glazing or varnish, and probably the colors, of porcelain bear to the shells used in some parts of the East instead of money (couries), and which, from the similarity of their shape to that of the back of a little pig, were also called *porcella.*

The possession of porcelain vessels afforded but little insight into the nature of their composition or the mode of their manufacture, as to which many unfounded theories were from time to time proposed. It was long believed, on the authority of Cardan and the elder Scaliger—who, although violently opposed to each other on various and more important subjects, yet agreed in this—that porcelain was made from a mixture of

* "About the end of the fifteenth century, cobalt appears to have been dug up in great quantity, in the mines on the borders of Saxony and Bohemia. As it was not known at first to what purpose it could be applied, it was thrown aside as a useless mineral. The miners had an aversion to it, not only because it gave them much fruitless labor, but because it often proved prejudicial to their health, by the arsenical particles with which it was combined; and it appears even that the mineralogical name *cobalt* then first took its rise. Frisch derives it from the Bohemian word *kow*, which signifies metal; but the conjecture that it was formed from *cobalus*, which was the name of a spirit that, according to the superstitious notions of the times, haunted mines, destroyed the labors of the miners, and often gave them a great deal of unnecessary trouble, is more probable. The miners perhaps gave this name to the mineral out of joke, because it thwarted them as much as the supposed spirit, by exciting false hopes and rendering their labor often fruitless. It was once customary to introduce into the church service a prayer, that God would preserve miners and their works from *Kobolts* and spirits."—*Beckmann*, *Hist. of Inventions*, vol. ii. pp. 341, 342.

broken egg and sea shells, which were preparatively buried in the earth for nearly a hundred years.

It was not until the beginning of the 18th century that any light was thrown upon the subject. At that time, the Jesuit, Francis Xavier d'Entrecolles, who was residing as a missionary in China, contrived to elude the jealous vigilance so generally practised towards strangers in that country; and not only obtained specimens of the earths used in the composition of their porcelain, but also acquired some knowledge of the processes employed in the manufacture at King-de-ching. A very circumstantial letter was written by the learned father on the subject, and published by Grosier in his general description of China: but owing to a want of practical knowledge on the part of D'Entrecolles, his descriptions proved so defective in many particulars, as to afford little or no assistance; besides which, it was not until some time after the publication of his letter that any substances similar to the earths transmitted by him could be discovered in France.

About the same time, and while the acquisition of these Chinese specimens was exciting the celebrated Reaumur to their examination, and to the institution of a series of experiments which will be hereafter mentioned, an incidental discovery made by the baron de Botticher, a German alchemist, occasioned the establishment of the porcelain manufacture in Saxony. While prosecuting his vain experiments in search of the philosopher's stone, this man prepared some crucibles, which he observed were caused by the action of heat to assume all the characteristics of Oriental porcelain. Blinded by the avarice which prompted their visionary labors, the adepts of that day seem generally to have turned away from the important discoveries that courted their notice, and which were thus reserved to reward the patient investigations of more philosophic minds in latter times. From this reproach De Botticher is free. The importance of the real discovery thus made was sufficiently apparent, and he had the wisdom to abandon immediately his former pursuit, and to give up the energies of his mind to the establishment of a manufacture, which was, in the end, productive of more beneficial results to himself and to his country, than if he had indeed been successful in his alchemical labors. The world at large did not immediately reap the full benefit of this discovery, as, with a jealousy but too common, the processes used in the Dresden works were veiled in impenetrable secrecy. Up to the period of De Botticher's death, in 1719, only white porcelain was made in Saxony; yet the success with which this manufacture was accompanied, occasioned attempts at imitation in France; and

porcelain works were established at St. Cloud, and in the Fauxbourg St. Antoine at Paris—the fabrics produced in which, although of beautiful external appearance, were wanting in most of the qualities essential to good porcelain.

The investigations of Reaumur, already alluded to, were undertaken with more rational views, and prosecuted with a more liberal feeling. The result of his researches was communicated by him to the Academy of Sciences, and published by that body in 1727 and 1729. Having procured specimens of Oriental, Saxon, and French porcelains, and broken them, he proceeded to examine their internal structure. The grain in both the Chinese and Saxon pieces appeared compact, smooth, and shining; while that of the French ware was less close and fine, without lustre, and its grain resembled sugar. He next proceeded to ascertain their habitudes on exposure to great heat in a crucible, and reported, that all the European specimens were melted, while that of China remained unaltered. This most essential difference led Reaumur to discover the true nature of porcelain, which is a semi-vitrified compound, in which one portion remains infusible at the greatest heat to which it can be exposed, while the other portion vitrifies at that heat, and enveloping the infusible part, produces that smooth, compact, and shining texture, as well as transparency, which are distinctive of true porcelain. Macquer, in his Chemical Dictionary, asserts, that Reaumur was wrong in classing the Saxon manufacture with the other fusible porcelains of European production; since the materials of which it is composed have always been similar to those of which the China ware is made, one portion being absolutely infusible during the baking.

In his examination of the two porcelain earths received from China, which are called in that country pe-tun-tse and kao-lin, Reaumur made a small cake of each substance, separately, and exposed both to the heat of a porcelain furnace. One, the pe-tun-tse, was fused by this means, without any addition; while the other, kao-lin, gave no sign of fusion. He next intimately compounded the two earths, and found, when the mixture was baked, that it had acquired all the qualities of the finest Chinese ware.

All that was then wanting for the perfect imitation of this admired production was the discovery of materials analogous to the specimen furnished by D'Entrecolles. The search for these was very speedily successful; and the manufacture of porcelain having, from this time, been taken under the royal patronage in France, the works of Sevres produced specimens

of art which vied successfully with those of Dresden and China.

Mr. Jonas Hanway, in the account of his travels published in 1753, has given a detailed account of the immense collection of porcelain deposited in the Chinese palace at Dresden.

"The vaults of this palace," says Mr. Hanway, "consist of fourteen apartments filled with Chinese and Dresden porcelain. One would imagine there was sufficient to stock a whole country; and yet they say, with an air of importance, that a hundred thousand pieces more are wanted to complete the intention of furnishing this single palace.

"Here are a great number of porcelain figures of wolves, bears, leopards, &c.—some of them as big as the life—a prodigious variety of birds, and a curious collection of different flowers. A clock is preparing for the gallery, whose bells are to be also of porcelain: I heard one of them proved, and think they are sufficient to form any music; but the hammers must be of wood.

"Here are forty-eight large China vases, which appear to be of no use, nor any way extraordinary, except for their great size; and yet his Polish majesty purchased them of the late king of Prussia at the price of a whole regiment of dragoons."

One part of this collection must have been peculiarly interesting, as it exhibited, in an orderly arrangement, specimens of Dresden manufacture laid up by this king of Poland, from the first efforts of De Botticher, through every subsequent gradation; "an idea," says Mr. Parke, "truly philosophical, and which reflects more honor on his memory than the bartering away the liberties of his subjects for pieces of foreign porcelain."

Frederick the Great, when he conquered Saxony, forcibly carried away several of the best workmen from the manufactory at Meissen, near Dresden, and conveyed them to Berlin, where, since that time, a considerable quantity of very good porcelain has been made for the private advantage of the monarch. As many as 500 men are constantly employed in this establishment; but although much of their material is drawn from Saxony, the Prussian porcelain has never equalled in quality that of Dresden.

It is generally believed, that since the time when they were first established by the Romans, potteries have always existed in Staffordshire, but it is certain that until the beginning of the eighteenth century the manufacture was confined to a few objects of the commonest and coarsest description.

The district in this county wherein the great bulk of English manufactured earthenware is produced, is situated about

a mile from the borders of Cheshire. The potteries commence at a village called Golden Hill, and extend for a distance of more than seven miles, passing through other towns and villages to Lane End. The names of the places comprised in this district, intermediate between the two already mentioned, are Newfield, Smithfield, Tunstall, Longport, Burslem, Cobridge, Etruria, Hanley, Shelton, Stoke, Lower Lane, and Lower Delf. All these have formerly been sufficiently distinct from each other; but the increase of the staple manufacture of the district has called for the erection of so many new potteries and dwelling-houses, that their individuality has been lost, and to a stranger the whole presents very much the appearance of one large town. In every part of the kingdom, except the district itself, the whole are ranked under one general name—that of the Potteries. Etruria is the creation of the celebrated Josiah Wedgwood, by whom the place was thus named after one of the ancient Italian states, celebrated for the tasteful forms it gave to its pottery, specimens of which have materially promoted the improvement of our modern English wares.

In the year 1686, when Dr. Plot published a Natural History of Staffordshire, its traffic in earthenware was very unimportant—being carried on only by the workmen themselves, or by pedlars, who conveyed the pieces in baskets on their backs through the adjoining counties. About the time just mentioned (1690), two brothers, named Elers, came from Nuremberg, in Holland, and settled at Bradwell, where they made an improved kind of red ware, and introduced the art of glazing the vessels by throwing common salt into the oven at a certain period of the baking.* Every precaution was used by the brothers to keep their processes secret; and it is probable that this circumstance, joined to the success of the strangers, excited the enmity and jealousy of their neighbors to the degree which obliged them to leave the country. The pretext assigned for this persecution was the alarm occasioned by the fumes from their kilns during the time of glazing. These fears subsided, however, when the process was continued by their successor. This man, whose name was Astbury, had, it is said, become master of their secrets by a singular stratagem. Feigning to be of weak intellect, and assuming an appropriate vacuity of countenance, he obtained employment in the Bradwell works, and submitted to all the drudgery and contumely which were drawn upon him by his supposed imbecility. By

* The salt is decomposed by this means; and, rising in fumes, the alkali which it contains combines with the silica of the ware, and forms a true glass which covers the entire surface.

this course of proceeding, he was enabled, unsuspected, to acquire a knowledge of all that was done in the manufactory, and to make models for his own use of all the utensils.

The advantages of this method of glazing with salt were so apparent, that in a short time it was very generally adopted; and on Saturday, the day appropriated to this process, the thick fumes from nearly sixty potteries filled the towns to a degree which darkened the atmosphere, and covered the hills of the surrounding district.*

To Astbury is generally ascribed the introduction of white stone-ware, by the adoption of calcined flints in its composition. The popular version of the origin of this improvement states, that "while travelling to London on horseback, in the year 1720, Astbury had occasion, at Dunstable, to seek a remedy for a disorder in his horse's eyes; when the ostler at the inn, by burning a flint, reduced it to a fine powder, which he blew into them. The potter, observing the beautiful white color of the flint after calcination, instantly conceived the use to which it might be applied in his art."†

The merit of this man has been somewhat overlooked, while contemplating the greater claims to admiration possessed by his more philosophic successor in the course of improvement. That could have been no common mind, however, which led Astbury to the long-continued pursuit of his object, by means so humiliating; and which also enabled him, on the occasion just related, to seize upon a fact thus accidentally presented, and which, although of high importance to his art, might have passed unheeded before the eyes of many a common-place manufacturer.

The step thus made was of consequence in preparing the way for the far greater advances towards perfection, afterwards accomplished by Mr. Josiah Wedgwood. This extraordinary man owed none of his success to fortuitous circumstances. Devoting his mind to patient investigations, and sparing neither pains nor expense in accomplishing his aims, he gathered round him talented artists from different countries, and drew upon the stores of science for aid in pursuing the objects of his praiseworthy ambition. The early and signal prosperity whereby his efforts were attended, served only as a motive urging him forward to new exertions, and as the means for calling forth and encouraging talents in others, in a manner calculated to promote the welfare of his country. Previously to his time, the potteries of Staffordshire produced only inferior fabrics, flimsy as to their materials, and void of taste in their

* Parke, Chem. Cat. p. 125. † Parke, Chem. Cat. p. 126.

forms and ornaments—the best among them being only wretched imitations of the grotesque and unmeaning scenes and figures portrayed on the porcelain of China. But such have been the effects resulting from the exertions and example of this one manufacturer, that the wares of that district are now not only brought into general use in this country, to the exclusion of all foreign goods, which had before been largely imported, but English pottery has since been sought for and celebrated throughout the civilized world, and adopted even in places where the art was previously prosecuted. An intelligent foreigner, M. Faujas de Saint Fond, writing on this subject, says, "its excellent workmanship, its solidity, the advantage which it possesses of sustaining the action of fire, its fine glaze impenetrable to acids, the beauty and convenience of its form, and the cheapness of its price, have given rise to a commerce so active and so universal, that in travelling from Paris to Petersburgh, from Amsterdam to the further part of Sweden, and from Dunkirk to the extremity of the south of France, one is served at every inn upon English ware. Spain, Portugal, and Italy, are supplied with it; and vessels are loaded with it for the East Indies, the West Indies, and the continent of America."*

It is not among the least of Mr. Wedgwood's merits, that he overcame the disadvantages of a defective education; and, amid the calls of an incessantly active life, found time wherein to school his mind in all the discipline necessary for investigations purely scientific. The ample fortune which he acquired was ever ready for promoting the spread of knowledge, encouraging the efforts of genius, and lessening, as far as possible, the sufferings of his fellow-creatures. His charities, public and private, and especially in his own district, were exemplary and consistent. He gave life to many objects of public utility. The Trent and Mersey canal was undertaken and accomplished through his influence; and by the benefits it has produced to the district, and to its proprietors, has fully approved his wisdom in its promotion.

The principal inventions of Mr. Wedgwood were—1. His *table ware;* the merits of which are, that it has a dense and durable body, and is covered with a brilliant glaze, capable of bearing uninjured sudden and great vicissitudes of heat and cold. This ware, as it was capable of being manufactured with ease and expedition, could be sold at a cheap rate, and would still yield a handsome profit to the inventor. Its various qualities, so superior to any possessed by previous manu-

* Travels in England and Scotland (English translation,) vol. i. p. 97.

factures of either domestic or foreign production, caused this ware to be taken into immediate and universal favor with the public. Among others, the queen bestowed upon it the tribute of her admiration and patronage; commanded it to be called *queen's ware*—a name which it continues to bear to the present day; and honored Mr. Wedgwood by appointing him her majesty's potter.

2. A *terra cotta*, which could be made to resemble porphyry, granite, Egyptian pebble, and other beautiful stones of the silicious or chrystalline order.

3. *Basaltes*, or black ware. This was a black porcelainous biscuit, having nearly the same properties with the natural stone. It would emit sparks when struck with steel; was capable of taking a high polish; resisted acids; and would bear, without injury, a stronger degree of heat than even the natural basaltes.

4. *White porcelain biscuit*. This ware had a smooth, wax-like appearance, and was possessed of all the properties exhibited by the preceding invention, differing from it only in regard to its color.

5. *Bamboo*, or cane-colored porcelain biscuit, of the same nature as the preceding.

6. *Jasper*. This was also a white porcelainous biscuit, of exquisite delicacy and beauty, having in general all the properties of the basaltes, with this in addition,—that it would receive through its whole substance, from the admixture of metallic oxides, the same colors as those oxides communicate to glass or enamel in fusion. This peculiar property, which it shares with no other porcelain or earthenware body of either ancient or modern composition, renders it applicable in a very pleasing manner to the production of cameos, portraits, and all subjects that require to be shown in bas-relief; since the ground can be made of any color that may be preferred; while the raised figures are of the purest white.

7. A *porcelain biscuit*, possessing several properties that render it invaluable to the chemist, and which have occasioned this invention to be brought into general use in all laboratories. The ware is exceedingly hard, being little inferior in this repect to agate, whence it is peculiarly adapted for forming mortars. It resists the action of the strongest acids and of all corrosive substances, and has the further quality of being perfectly impenetrable by any known liquid.

The investigations of Reaumur, already detailed, make it evident that the characteristics of porcelain, as far as they depend upon semi-vitrification, may be obtained when ingredients wholly fusible are employed, provided the fire be care-

fully withdrawn from the oven at the precise moment when vitrification has arrived at, and not proceeded beyond, a certain point. Accordingly, this porcelain was, at one time, very commonly produced both in this and other countries. The quality of goods thus composed is always inferior to that of true porcelain; and, if further or again exposed to the heat of the furnace, the substance would entirely change its nature, and run into a vitreous and shapeless mass.

Porcelain of this description, much esteemed for its beauty, was long manufactured at Bow and at Chelsea. It was not until the year 1768, that Mr. Cookworthy discovered certain mineral substances in Cornwall similar in their properties to the porcelain earths of China; and having secured to himself, by patent, the exclusive right of using those materials, was the first person who made true porcelain in England.

In practising this art, Mr. Cookworthy, and those to whom he afterwards assigned his patent right, attained to considerable success as regarded the quality of their manufactures, although the demand for their goods did not prove proportionate to the money expended in bringing the processes to perfection. One probable cause for the inadequacy of their remuneration, existed in the successful efforts of Mr. Wedgwood, which have been already detailed, for improving the quality of common earthenwares made in Staffordshire, whereby foreign porcelain was rendered less an object of desire, and consequently its successful imitation was no longer considered as being of any great importance.

The extent to which, in the year 1785, this manufacture had arrived, and its importance to the three great interests of the country—landed, maritime, and commercial—may be collected from the evidence then given by Mr. Wedgwood before a committee of the privy-council, and at the bars of the two houses of parliament. The question at that time under the consideration of the legislature, and upon which these examinations were taken, arose out of the proposal of government to abolish the system of commercial restrictions and disabilities then existing between Great Britain and Ireland, and to render the intercourse between the two divisions of the empire nearly as free and unrestricted as that between the counties of Durham and Northumberland; a proposition so perfectly natural and reasonable in itself, that, but for the possession of records wherein they have been preserved, we might really be at a loss to conjecture the nature of the arguments whereby it was opposed and defeated.

In the course of the discussions to which this subject gave rise in the house of lords, the marquess of Lansdowne, remark-

ing upon the evidence given by the respectable merchants and manufacturers at the bar of the house, declared that the result to which he in his own mind had arrived was the very opposite to the conviction which they had adopted. "Though much valuable information may," said his lordship, "doubtless, be derived from their evidence, it must not be forgotten that they are men peculiarly subject to prejudice and error, in all cases where their personal interests are concerned. Were any one, for instance, to ask a manufacturer of Halifax, what is the greatest crime upon earth? Is it felony, is it murder, is it parricide? No! he would answer; it is none of these—it is the exporting of WOOL."

In later times, we have seen this measure of justice and sound policy more successfully brought forward; and it is acknowledged that each country has since been reaping benefits in consequence, upon the inevitable arrival of which nothing but the strongest commercial prejudices and national jealousy could have thrown even a momentary doubt.

Mr. Wedgwood, in the course of the evidence already alluded to, thus remarks:—"Though the manufacturing part alone in the Potteries, and their immediate vicinity, gives bread to 15 or 20,000 people, yet this is but a small object when compared with the many others which depend on it; namely, 1st, The immense quantity of inland carriage it creates throughout the kingdom, both for its raw materials and finished goods. 2d, The great number of people employed in the extensive collieries for its use. 3d, The still greater number employed in raising and preparing its raw materials in several distant parts of England, from near the Land's End, in Cornwall—one way along different parts of the coast, to Falmouth, Teignmouth, Exeter, Pool, Gravesend, and the Norfolk coast; the other way to Biddeford, Wales, and the Irish coast. 4th, The coasting vessels, which, after having been employed at the proper season in the Newfoundland fishery, carry these materials coastwise to Liverpool and Hull, to the amount of more than 20,000 tons yearly; and at times when, without this employment, they would be laid up idle in harbor. 5th, The further conveyance of these materials from those ports, by river and canal navigation, to the Potteries, situated in one of the most inland parts of this kingdom; and, 6th, The reconveyance of the finished goods to the different parts of this island, where they are shipped for every foreign market that is open to the earthenwares of England."

Mr. Wedgwood very justly observed further, that this manufacture is attended with some circumstances of advantage which are almost peculiar to itself; viz. that the value of the

finished goods consists almost wholly in the labor bestowed upon them; that every ton of raw materials produces several tons of merchandise for shipping, the freight being paid, not upon the weight, but according to the bulk; that scarcely a vessel leaves any of our ports whose lading is not in part made up of these cheap, bulky, and, for these reasons, valuable articles, to this maritime country; and that fully five parts in six of the aggregate manufactures of the Potteries are exported to foreign markets.

Important as were the advances which at that time had been made in the art, Mr. Wedgwood was still of opinion that they could be considered but as the beginning of improvements,—that these were still but in their infancy, and but of little moment when compared with those to which the art was capable of attaining, through the continued industry and growing intelligence of the manufacturers, in combination with and fostered by the natural facilities and political advantages enjoyed by the country; an opinion fully borne out by the event, and which our progressive experience shows to have been founded on clear and accurate perceptions.

The manufacture of earthenwares in England is far from being restricted to the district in Staffordshire which has been described already as having acquired the name of "the Potteries." Establishments for making the commoner kinds of wares are to be found in many and various parts of the kingdom; at Lambeth, especially, several manufactories of stone pottery have been carried on for considerably more than a century, producing articles which have never been surpassed in any country, either for the excellence of their materials and workmanship, or for the magnitude of the vessels and the variety of uses to which they are adapted. The Lambeth ware may, in fact, be pronounced perfect of its kind.

Porcelain has long been made at Derby, and at Coalport, near Colebrook Dale, in Shropshire. Establishments have subsequently risen in the city of Worcester, wherein very beautiful specimens are produced; and yet more recently, the manufacture of excellent porcelain has been engrafted upon a long-established pottery for commoner wares, situated at Swinton, near Rotherham, in Yorkshire. At the Rockingham works, which have been so named in compliment to their early patron, the celebrated marquess of Rockingham, porcelain is now produced which vies successfully in every kind of excellence with that of older English establishments. Among many other specimens which attest the proficiency of the Yorkshire manufacturers, two may be more particularly mentioned, which are deserving of more than common attention as denoting the

degree of advancement to which the art has reached in England.

One of these pieces is a copy in enamel colors, made on a porcelain tablet, from an original painting by Vandyke, and now in the possession of the noble inhabitant of Wentworth Castle. The subject of the picture is, "The earl of Strafford occupied in dictating his defence to his secretary." The execution of this copy does justice to the masterly original; and, in regard to expression and coloring, has been pronounced equal to the most admired productions of the Sevres works. The other specimen is remarkable not only for elegance of design, and the goodness of the workmanship, but also because it is believed to be the largest piece of porcelain that has hitherto been made in this country. It is a scent-jar, forty-four inches high, made and fired in one entire piece. The base, or plinth, is triangular, having a circular projection at each angle; from these rise lions' paws, upon which the globular body of the jar is supported. The scent is allowed to escape through hexagonal openings in the neck. The jar is divided into three compartments, by as many rustic handles of knotted oak; while branches of the same tree, with their rich foliage rising from the plinth, are spread tastefully over the lions' paws, and thence entwining with the handles, rise and encircle the base of the neck. The ornaments of the cover are in keeping with those of the jar, it being covered with branches and foliage of the oak: the whole is surmounted by the figure of a rhinoceros. The three compartments into which the jar is divided are enriched with highly finished paintings in enamel colors, executed by one of the proprietors of the works, from designs by Stothard, the subjects of which are drawn from the admirable romance of Cervantes. The circular projections at the base, and the cover, are adorned with paintings from nature, of six subjects of rare botanical plants, the originals of which are in the conservatories of Wentworth Castle. The whole is relieved and enlivened by ornamental work, in burnished and chased gold; and the work, both in its design and execution, is highly honorable to the artists.

Up to a comparatively recent period, the manufacture of earthenwares formed one of the very few branches of domestic industry which were left free from the evil effects of direct taxation, and, except in one branch, of very minor importance, the art is still in the enjoyment of this immunity; to which favorable circumstance may be imputed much of the signal and uniform success whereby it has been attended. In the year 1812, when the duty upon glass bottles was doubled, the manufacturers of these represented to the chancellor of the ex-

chequer, that unless a countervailing tax were levied upon stone bottles, the latter, being wholly unburthened, would possess an unfair advantage, and might be sold at prices that would drive glass bottles out of use. This was a line of argument in no wise unpalatable to the minister, who readily caught at the suggestion of a new object for taxation; and a duty of five shillings on each hundredweight was immediately imposed upon all stone bottles the content of which should be two quarts and under.

The levying of this duty calls for the attendance of revenue officers at all hours on the premises of every stoneware manufacturer throughout the kingdom; and it is very much to be doubted whether, in any one year since its first imposition, the expenses of collection have not more than absorbed the whole amount paid by the potters. The total quantity of stoneware made which is chargeable with the duty does not exceed 600 tons annually, and a large proportion of this is used for purposes to which glass has never been applied. It is not very likely that stoneware, the utility of which for many purposes is exceedingly great, would ever have been brought into competition with a material so much lighter, and in many respects so much more convenient, even had the pottery continued free from the domiciliary visits of the exciseman; and now that the experiment has been fairly tried during nearly twenty years, and has been found unproductive of any real revenue, there can be no sufficient reason for continuing the impost.

CHAP. II.

GENERAL DESCRIPTION OF INGREDIENTS USED IN THE MANUFACTURE.

Different branches of the art.—Ingredients used.—Properties of Alumina.—Its infusibility.—Contraction when exposed to heat.—Wedgwood's Pryometer.—Composition of Gems.—Great abundance of Clay.—Properties of Silica.—Its great abundance.—Sea sand.—Incapable of artificial solution in water.—Dissolved naturally.—Springs at Carlsbad.—Boiling fountain in Iceland.—Fusion of Silex.—Kinds of Clay used in Potteries.—Their various merits.—China clay of Cornwall.—Mode of its preparation.—Its analysis.—Cornish Felspar.—Its fusibility.—Steatile.—Earth of Baudissero.—Its analysis.—Cornish sopestone.—Spuma maris.—Its employment in porcelain works in Spain.

The art of manufacturing pottery and porcelain naturally divides itself into four different and distinct branches: the first of these comprehends a knowledge of the nature and peculiar properties of the various materials, whereof the vessels are composed; the second comprises the methods used in combining these materials, and in fashioning the vessels; the third branch

includes the choice and management of the colors and enamels employed in painting and ornamenting the wares, together with the operations necessary for their conversion; and the last division embraces the means required for completing the manufacture by the aid of fire. In describing, however, the different stages of the manufacture as they occur, the painting and baking processes must unavoidably be intermingled.

The chief ingredients employed in the composition of all kinds of pottery are clay and flint: these are both classed by chemists among the primitive earths. The first of them, in its state of purity, is denominated *alumina*, or oxide of aluminum; and the latter is called *silica*, or oxide of silicium. It is only since the year 1754 that alumina has been acknowledged as a peculiar substance; and the period is much more recent when the researches of Davy proved it to belong to the class of metallic oxides.

It is of great importance to make choice of a suitable kind of clay for the manufacture; but, according to the remark of the celebrated Vauquelin, it is much more important to combine this with a due proportion of flint, as good pottery differs from that which is inferior less in the original quality of its elements than in their proportions.

Clay is an opaque and non-crystallized body, of dull fracture, soft enough in all states to take a mark from iron; when breathed on it exhales an odor which, from its peculiarity, takes its name from the material, and is termed argillaceous. This is owing to the oxide of iron which is mixed with it, as clay, when absolutely pure, does not emit any odor. Clay forms with water a plastic paste, having considerable tenacity, and which, by the action of heat, is brought to a very great degree of hardness: it is compact, smooth, and almost unctuous to the touch, and when dry, may be easily polished by the finger. It is not soluble in water, but mixes readily with it in all proportions, parting with difficulty from the last portion of that which it has absorbed: it will adhere to the tongue. The description of clay employed by potters is infusible in the heat of a porcelain furnace, where some kinds, owing to their being combined with oxide of iron, assume a red color, while others become of a pure white. The highest temperature to which clay can be exposed tends only to increase its density, hardening its substance and diminishing its volume. This diminution of volume produced by increased temperature is an apparent deviation from the general law of expansion by heat; but the deviation is only apparent, and is probably produced by the vaporization of liquid, combined with the clay. Mr. Wedgwood found that the diminution of volume produced by exposing the clay to these ex-

treme temperatures, continued the same after the clay was suffered to cool, and therefore that its amount admitted of deliberate and accurate measurement. He also supposed (though erroneously) that the shrinkage of the clay was always proportional to the temperature to which it had been exposed. This led to his well-known invention of the pyrometer, an instrument for measuring degrees of temperature beyond the range of the common thermometer. The instrument consisted of small cylinders, composed of two parts of the porcelain clay of Cornwall, and one part of pure alumina. These, when baked in a low red heat and then cooled, were constructed of such a size as just to enter between the wider extremities of two brass rods, fixed on a plate twenty-four inches long, half an inch asunder at one end, and three-tenths of an inch at the other. These rods were divided to tenths of an inch, and consequently each division formed the 240th part of the whole length. The clay cylinders, being exposed to the heat which was required to be determined, were subsequently inserted between these bars, and by reason of their contraction they advanced between them to a point depending on the amount of their shrinkage.

This pyrometer, however, has been found to be subject to a fatal defect. The shrinkage of the clay does not depend on the temperature alone of the fire to which it is exposed, but also on the length of time which the fire has acted upon it. Thus a lesser degree of heat will produce the same shrinkage as a greater degree, provided the clay is exposed to the former for a longer portion of time. The instrument has been, consequently, long since totally laid aside.

Some of the most valued among the precious stones, such as rubies, sapphires, emeralds, jaspers, and others, are composed of either alumina or silica, or of the two earths in combination, together with different small portions of lime, or oxide of iron, or magnesia, &c. The different kinds of clay are most abundantly spread over the globe, forming in many situations entire mountains, in other places existing in vast beds, and elsewhere lying among other mineral substances disposed in strata. It has been generally held that clay results from the slow decomposition of silicious and aluminous rocks, which being acted on by water filtrating through them, their constituent parts have, in the course of ages, been separated; the lighter and finer portions remaining united at the top, while the grosser but less tenacious parts have been resolved into sandy deposits.

Silica, or pure flint, which forms the second material in the composition of pottery, has been considered as a primitive earth. It is of very common occurrence in most parts of the world, in

primitive mountains. It is frequently found in great abundance embedded in chalk. In Scotland and Ireland it occurs in secondary limestone. Flint abounds in alluvial districts in the form of gravel: an inexhaustible supply of excellent quality might be collected on some parts of the sea-coast of England, and particularly at and near Brighton, where there is enough of this material, known under the name of shingle, to serve the whole manufacturing wants of England for ages to come, while its removal would be attended with advantage to the place whence it should be taken. Flint is silica in a state nearly approaching to purity, its constituents being

Silica	98.
Lime	0.50
Alumina	0.25
Oxide of iron .	0.25
Loss	1.
	100.

It is usually gray, with occasional striped delineations occurring in its substance. It it obtained generally in rolled pieces, but often occurs in irregular shapes. It has internally a glimmering lustre; its fracture is conchoidal, and its fragments are sharp-edged. It is translucent. When two pieces are rubbed together in the dark, they emit a phosphorescent light, and give off a peculiar smell. We are unable to dissolve silex in water. This process is, however, constantly performed by nature. The investigations of Klaproth enabled him to detect 25 grains of silex in 1000 ounces of the principal mineral spring at Carlsbad, in Bohemia; and the celebrated boiling fountain at Rykum, in Iceland, deposits so considerable a quantity of silicious earth, that a solid cup has been formed around it, rising to a considerable height. This solution of silica is probably owing, in both these cases, to the solvent power of soda; which is also present in the water. The water from the spring at Rykum used formerly to be projected into the air to the perpendicular height of 60 or 70 feet; but the overthrow of a mass of rock having since partially covered its orifice, the stream spouts out laterally to a distance of 50 or 60 feet. The heat of the liquid, after it has reached the surface, is sufficient to raise the thermometer to the boiling point of water; and there is little doubt that the fluid must have parted with some portion of its heat on emerging into the atmosphere. The capability of water, in its dense or liquid state, to assume, under these circumstances, a higher degree of heat than that at which it boils under ordinary atmospheric pressure, may be partly at-

tributable to the depth from which it is brought, influenced by the same law that occasions fluids to boil at lower temperatures on the tops of high mountains. Silica is also found existing in solution in the Bath waters.

The best flints are of a dark gray color, approaching to black, and having a considerable degree of transparency. Those which exhibit brown or yellow spots on their interior surfaces should be rejected, on account of the ferruginous particles which they contain, and which would occasion blemishes in the ware. Those larger masses of flint are always most preferred by the potter, which, being dark and clear within, are covered with a white crust externally. The rolled pieces which are taken from chalk pits are mostly of this description.

De Saussure asserts that pure silex may be fused at a heat equal to 4043 degrees of Wedgwood's pyrometer; a degree so far beyond any that has yet been observed, that one is at a loss to know upon what data the assertion is founded.

The clay principally used in the potteries of Staffordshire is brought to them from Dorsetshire and Devonshire. These earths are both of excellent working quality, and, being free from any impregnation of iron, are valuable for the great whiteness which they exhibit when burnt. The Dorsetshire clay is brought from the Isle of Purbeck. It is of two kinds, distinguished as brown clay and blue clay: that from Devonshire comes from the southern part of the county, and is also of two distinct qualities, which are known as black clay and cracking clay. The clay from Dorsetshire is considered preferable to that from Devonshire for the potter's use; so that it commands a price in the potteries equal to one eighth more than the latter.

The good qualities of brown clay are, that it burns of an excellent white, and is not liable to crack during the process of burning. On the other hand, it is subject to the considerable imperfection of *crazing*,—an evil which induces some manufacturers to discard it altogether from their works. Crazing is a technical phrase, used to denote the cracking of the glaze, which is believed to arise from the imperfect manner in which this is capable of uniting itself with the clay composing the body of the vessel. This defect of crazing is not, however, always referable to the cause here assigned, but may be owing equally to the faulty nature of the glaze, which may not be capable of perfect fusion in the heat of the kiln; or it may result from the error of the workmen in withdrawing the wares from the kiln at too early a period, and before they are properly cooled; the glaze, which is in fact glass, requiring great carefulness in this respect for its proper annealing, and being, with-

out it, very liable to crack with every material variation of temperature to which it may be suddenly exposed.

Blue clay combines the greatest number of good qualities, and is the most generally esteemed, of all the four descriptions here mentioned. It burns exceedingly white, forms a very solid quality of ware, and is capable of being advantageously combined with a greater quantity of silicious earth, or flint, than any of the other kinds; a quality which is desirable, because the greater the proportion of silica that is used, the whiter will prove the ware: the limit to the use of flint being the inability of the clay to bear it in combination beyond a certain proportion without cracking. Both these descriptions of clay are much used as ingredients in the manufacture of porcelain.

Black clay owes its distinctive color to the quantity of coaly or bituminous matter which it holds in combination, but which is entirely consumed and dissipated when the clay is submitted to the heat of the oven, leaving the articles of which it is composed of a very good white; and which is, indeed, found to be the more perfect in proportion as the clay has originally been blacker. Cracking clay has acquired its name from an evil property of occasioning the ware to crack while undergoing the first application of fire. To compensate in some degree for this evil, the goods in which it is employed prove of an extreme whiteness. Much judgment and experience must be brought to the employment of this clay, that its tendency to cracking may be as much as possible corrected by a proportionate admixture. If clay of any description were dried without the addition of any other body, after being made sufficiently plastic to be modelled on the potter's wheel, it must inevitably crack, as the evaporation of its water will occasion it to shrink in the proportion of one part in twelve during the drying.

Another description of clay, much prized for the manufacture of finer kinds of earthenware and porcelain, was found in Cornwall by Mr. Cookworthy, as already mentioned, and is commonly denominated China clay. This is very white and unctuous to the touch, and is obviously formed by the gradual disintegration of the felspar of granite. There are found in Cornwall large mountains of this mineral, some of which are thus partially decomposed; this China clay proves, on examination, to be identical with the kao-lin of the Chinese. It was found by Mr. Gerhard in the course of some experiments upon granite (which is a compound of quartz, felspar, and mica,) that the felspar was melted into a transparent glass, that the mica was found lying under it in the form of a black slag, while the quartz remained unaltered.

The China clay of Cornwall is prepared by the clay mer-

chants on the spot where it is found. The stone is broken up into pieces of a small size, and then cast into a running stream: there the light argillaceous parts are washed off and held suspended in the water, while the more ponderous mica and quartz remain at the bottom of the stream. At the end of the rivulet the water is stopped by a dam, and the pure clay gradually subsides. When this deposit is completed, the clear water is drawn off, and the solid matter dug out in square blocks, which are placed on shelves, and exposed to a continued current of air until sufficiently dry to be packed in casks for shipment. This clay, which is then in the state of a fine powder, is very smooth, and of an extreme whiteness. Mr. Wedgwood found by analysis that it contains sixty parts of alumina and twenty parts of silica. The manufacturers are required to pay a much higher price for this than for any other of our native earths, but for some finer purposes it is altogether indispensable.

A portion of undecomposed Cornish felspar is often added to the clay, on account of its fusibility and tenaciousness, by which it binds, as it were, the whole ingredients more closely together. The fusible quality of felspar is owing to the presence of about an eighth part of potass. If this alkaline substance be separated by decomposition, as is the case with the China clay above described, the fusibility no longer exists, and the body remains unaltered in the greatest heat of a porcelain furnace. The use of this material has of late been very much increased in our porcelain works. It is a curious and very useful fact, that although neither clay, flint, nor lime can be separately melted, yet when mixed together in due proportions, the mass is fused without difficulty, the one mineral acting as a flux to the other.

Steatite, or soapstone, has of late years been very much employed in the composition of porcelain. When present, in even a small proportion, it limits the contraction of the ware in the furnace. Steatite is a sub-species of mica, which is found abundantly in Cornwall, and is met with also in the island of Anglesea. The mineral which forms the porcelain earth of Baudissero, was long considered to be a superior kind of clay, until it was discovered by M. Geobert that it contains not a particle of alumina in its composition. This chemist, on endeavoring to convert the substance into alum, found, to his great surprise, that he obtained only crystals of sulphate of magnesia (Epsom salts). Proceeding thence to analyze it carefully, he ascertained its composition to be, magnesia 68, carbonic acid 12, silica 15·6, sulphate of lime 1·6, water 2·8. The soapstone of Cornwall differs from this substance, yielding on analysis, magnesia 44, silica 44, alumina 2, iron 7·3, magnesia 1·5, chrome 1·2. It also contains traces of lime and muriatic acid.

In a published letter addressed by M. Proust to M. Vauquelin from Madrid, mention is made of a beautiful kind of porcelain produced in that city, and which is described to be of a texture even harder than the porcelain of France. Instead of employing the kao-lin, the body of the ware is made with spuma maris, a species of pot-stone found in the neighborhood of Madrid, and the glaze is composed of felspar brought from Gallicia. The pot-stone when taken from the quarry is sufficiently soft to admit of its being cut with a knife like soap. Besides magnesia, silex, and some particles of argil and lime, it contains a portion of potass, the presence of which, in the competent opinion of M. Proust, contributes not a little to the superior quality of the manufacture.

CHAP. III.

ON THE PREPARATION OF MATERIALS.

Dilution of Clay.—Chemical Examination of Water necessary.—Rain Water.—Carefulness of German Manufacturers.—Blunging.—Machinery.—Preparing Flints.—Burning.—Breaking.—Grinding.—Dry Grinding.—Brindley's Improved Mill.—Chert.—Care required in selecting Grinding Stones.—Dilution of Flint-Powder.—Proper Consistence of Dilution.—Admixture in due Proportions.—Affinity of Alumina for Silica.—Slip.—Slip-Kiln.—Method of evaporating superfluous Moisture.—Working the Paste.—Time necessary for tempering it.—Proportions wherein Clay and Flint are united.—Difficulty of ascertaining this.—Slapping.—French Manufacturers.—Proportions of Ingredients used by them.—Kao-Lin.—Flint.—Gypsum.—Broken Porcelain.—Calcined Bones.—Tender Porcelain.—Its Composition.—Porcelain Earth used in Berlin.—French Potters buy their Materials ready mixed.—Advances on this Plan.—Ineligible in England.

In preparing the clay, the first operation of the pottery is that of mixing it with water to the consistence of cream. It is well known, that water collected from springs, and from many streams, contains various foreign matters, some of which would be injurious to the composition of porcelain. It is therefore necessary to examine chemically the properties of water before it is employed for this purpose, in order to make choice of that which is purest; and to correct, by some of the well-known means, any bad qualities that may be present. The French manufacturers are accustomed to employ only rain water, whose near approach to purity fits it for the object. In Germany, still more precise in his operations, the manufacturer prepares his materials only twice in the year, at the vernal and autumnal equinoxes; persuading himself that at these seasons there is some peculiarity in the rain which better qualifies it for

the purpose of his manufacture. Although the grounds for this nicety are not apparent, it would savor of presumption to attribute the practice entirely to prejudice. The observations of men practically engaged in manual or chemical operations have frequently led to improvements in processes, long before the reasons whereon these should have been founded have been revealed by scientific researches.

The mixing of the clay, which is called *blunging*, is effected in a trough five feet long, three feet wide, and two and a half feet deep. In order fully to break down the clay, and incorporate it with the water, a long wooden instrument, formed with a blade at one end and a cross handle at the other, is moved violently about in the trough in all directions; and this becomes an operation of great labor. In large establishments, where machinery is adopted for the abridgment of labor, the blunging is thus effected:—The clay is thrown into a cast iron cylinder, four feet deep, and twenty inches in diameter. Through the centre of this cylinder runs an upright shaft, furnished with knives placed as radii at right angles to the shaft, but so arranged upon it that their flat sides are in the plane of a spiral thread, so that by the revolutions of the shaft, the knives perform the double office of cutting whatever stands in their way, and of forcing downwards the contents of the cylinder in the manner of a screw. Another set of knives is inserted in the interior surface of the cylinder, and these extend to the shaft in the centre, parallel to, and corresponding with, the revolving knives: thus the two sets, the one active and the other passive, have the effect of shears in cutting the clay into small pieces; while this, in its reduced state, is at the same time forced through an aperture at the bottom of the cylinder, and transferred to a vat for the purpose of being mixed with water; a process which this previous dividing of the clay is found materially to facilitate.

The vat where this mixture is performed is likewise of a cylindric form, its diameter being equal to four times its depth. In the centre of this vat, also, a perpendicular shaft is inserted, furnished with cross arms or radii, one below the other. These cross arms are connected by upright staves, giving the appearance of two opposite gates hung upon the central shaft. These revolve within the cylinder; and as they are partially immersed in the pulp, the constant agitation mixes all the finer particles of clay with the water, while stony particles of greater magnitude fall to and remain at the bottom. The pulp, now mixed to the consistence of cream, is passed off from the vat through a series of sieves of increasing degrees of fineness, which are worked to and fro by machinery; thus a separation is effected

between the grosser parts and that portion which is fitted to enter into the composition of the ware.

The next process is that of preparing the flints. These are first burnt in a kiln constructed for the purpose, and which very much resembles an ordinary lime-kiln, being of a conical shape, and about nine feet deep. While the flints are yet red-hot, they are removed from the kiln, and in that state are thrown into cold water; by means of which their attraction of aggregation is lessened, so as to facilitate greatly the subsequent operation of grinding: they are next broken, either by manual labor, or by machinery. In the latter case they are placed upon a strong iron grating, and there struck by hammers, until sufficiently reduced in size to fall through the grating to a receiver, whence they are conveyed to the flint mill.

In order to expedite the process, and at the same time to grind the flints finer, a quantity of water is thrown with them into the mill. Another good attending the presence of water in this grinding operation, is the preservation of the health of the workmen. Before the adoption of this method, the atmosphere of the room became charged with the finer particles of flint, which, adhering to the lungs, frequently occasioned distressing and sometimes fatal diseases to the workmen. This great improvement was effected by the illustrious Brindley, who likewise invented the mill now used in the process. This is a large circular vat, about thirty inches deep, having a central step fixed in the bottom to carry the axis of a vertical shaft. The moving power is applied to this shaft by a crown cog wheel placed on the top. At the lower part of the shaft, and at right angles to it, are fixed four arms, upon which the grinding stones are fixed; large blocks of stone of the same kind being likewise placed in the vat. These stones are a very hard silicious mineral, called chert, which is found in abundance in the neighborhood of Bakewell, in Derbyshire. The broken flints being then introduced and completely covered with water, the axis is made to revolve with great velocity, when the calcined flints are speedily reduced to an impalpable powder.

The nature of the grinding stones used in these flint mills is of considerable importance; for should they contain any calcareous carbonate, they will be abraded; some part of their substance will mix with the flint, and consequently with the body of the wares, and thus occasion very serious injury to the manufacturer. Some years ago, a very heavy loss was sustained by some potters, who had purchased flints ground in a mill the stones of which contained carbonate of lime.

When the flints are thus sufficiently ground, the semi-fluid

is transferred to another vat, also constructed with an upright shaft furnished with arms or [illegible] for the purpose of agitation; and a considerable quantity of water being added, the moving power is applied, and the whole violently agitated. The process occasions the grosser and weightier particles to take their place at the bottom, while the finer [illegible] remains in suspension above; and in this state is passed [illegible] to a reservoir, whence in due time the supernatant water is drawn off through apertures provided for the purpose.

The dilution of clay is held to be of the proper consistence for mixing, when a quantity that will fill a pint measure weighs twenty-four ounces; and that of the flint is equally considered suitable for use, when the same [illegible] is brought to weigh thirty-two ounces. It is by these means, [illegible] that is, by the comparative densities of these dilutions, as ascertained by weighing an equal bulk of each, that the manufacturer is enabled to ascertain the real proportions of the materials, and to combine them in the degrees which his experience leads him to employ for the composition of various kinds of ware; [illegible] too much nicety can hardly be given to this important part of his labors.

The dilutions of clay and flint being brought together in suitable proportions, and intimately mixed by agitation, the mixture is passed, while in a state of semi-fluidity, through different sieves, in order to separate any remaining impurities, together with such portions as have not been sufficiently ground. By these means the mass presents the utmost uniformity and smoothness throughout. The affinity which alumina has for silica, under all circumstances, is so great, that they will unite even in the humid way, forming a kind of mortar; and when this becomes hardened by time, it is thereafter incapable of decomposition by the action of the atmosphere.

This fluid mixture of clay and flint is called *slip*, and after passing through the sieves, is pumped to the *slip kiln*. This is a kind of trough formed of fire-bricks; its size varies according to the extent of the manufactory, being of the length of forty to sixty feet, from four to six feet wide, and about twelve to eighteen inches deep. Flues from fire-places pass under the whole extent of the troughs, in which the fluid is made to boil, and the process of evaporation is slowly conducted, so as to produce an uniform consistency throughout the mass. This evaporation must be very carefully attended, and the mass frequently stirred and turned over, otherwise, from the imperfect manner in which it conducts heat, the portion in contact with the bricks would become improperly hardened, while the remainder would continue fluid; in addition to which, flint being

specifically heavier than clay, the former would in the first part of the process, and while the slip is yet fluid, have a natural tendency to subside to the bottom, and thus render the composition of the mass unequal.

The evaporation is never carried beyond a certain point in the kiln; for should the mass become too dry, it would be impossible to knead it properly, or to mould it on the wheel into any of the forms which it is desired to create. The place where this evaporation is performed is called the *slip-house*.

When the clay or paste is removed from the slip-kiln it contains a great number of air-bubbles, and must be well incorporated together or tempered by working or beating it with wooden mallets. It is next cut with a kind of spade into small pieces, which are thrown upon the mass with all the strength of the workmen, and these operations are persisted in until it is supposed that their further continuance would not bring the whole to a more complete state of consistence.

The mixture, when brought to this state, should be suffered to remain in a mass for a considerable time before it is used; the material by this course becomes much more intimately united than can ever be effected by mechanical means. It is to be feared that, although the English potters are fully aware of this fact, they yet fail to adopt so eligible a practice, which, as it calls for the employment of greater space, time, and capital, is neglected for other advantages, which, if not so great in an extended point of view, are certainly more immediate.

It is not possible to state the precise proportions wherein the clay and flint are brought together in our English potteries. Each manufacturer has in this respect his own practice, which, esteeming it as the best, he endeavors to keep profoundly secret; and, besides, the proportions necessarily vary with the quality and properties which it is desired to give to the manufacture. Vauquelin informs us that silex forms at least two thirds of all kinds of pottery; alumine from one fifth to one third; lime from 1-500th to 1-2000th part; and iron from the smallest conceivable quantity up to twelve and sometimes even fifteen per cent. The presence of the two latter bodies is accidental, arising from the natural composition of the materials, and in particular the oxide of iron, when present in any sensible degree, renders the clay unfit for all purposes, except that of forming the common red ware.

Parkes, whose practical essay on the making of earthenware and porcelain is founded on his own personal observations, made during a residence of some years' continuance at the seat of manufacture, is yet so little able to be precise upon the sub-

ject of proportions, that the tails or flint forms a fourth, a fifth, or a sixth part by weight of the prepared paste.

Some portion of the china-clay of Cornwall enters into the composition of every better kind of earthenware, except only the cream-colored sort. This ingredient is sometimes mixed in the mass, and blunged with it, and at other times is blunged separately and mixed in the required proportion with the slip.

The clay or paste, when taken for use, undergoes the process of slapping. This labor is performed by a man of considerable strength, who proceeds by taking a mass weighing from fifty to sixty pounds upon a convenient board or bench. The mass is then cut through with a thin brass wire, one end of which is held in either hand, while the part between is forced through the clay, which separates as easily as if it were cut with a knife; then taking up with both hands the piece thus separated, and exerting his utmost strength, he dashes it on the rest of the mass; and this operation is repeated until the whole lump exhibits a perfectly smooth and close appearance wherever it is cut. So complete is the incorporation of the whole mass by this means, that if at the commencement of the process, two pieces of clay of different colors are taken, the lump, at its completion, will be of one uniform hue, intermediate to the two original colors. This laborious operation is one of the very first necessity, in order completely to expel every air-bubble, however minute, remaining in the clay, and which could not be so thoroughly driven out by its previous beating in the larger mass when taken from the slip-kiln. If the air were not thus thoroughly expelled, it would become so much rarified and expanded in the oven, that it would force out a passage for itself, and by blistering spoil or much injure the goods.

Some of the more considerable among the potters, who employ steam power for blunging the clay and grinding the flints, perform this operation of slapping by the same agency, saving thereby both time and labor. In this case the expulsion of the air is effected by mechanical pressure, and the office is performed with perhaps as much efficiency as by hand.

Having undergone all these preparations, the clay is now fit for being shaped upon the wheel or fashioned by the aid of moulds into all the diversified forms which fancy may desire. This branch of the art is divided into three different departments—throwing, pressing, and casting—either of which is used according to the form of the article manufactured.

The manufacturers of porcelain in France do not use so much secrecy as is preserved in our own potteries, with respect either to the materials whereof their ware is compound-

ed, or to the proportions wherein these are employed. The clay which forms five parts in six of the whole mass, is the porcelain earth already mentioned as being identical with the kao-lin of China; to this are added in certain proportions flint and gypsum (plaster of Paris), both calcined and ground; and fragments of broken porcelain, which must be white, also ground to a fine powder. One rule for forming this composition assigns nine parts each of flint and broken porcelain, and four parts of calcined gypsum, to each one hundred parts of porcelain clay. Another authority recommends five parts of gypsum and only eight parts of ground porcelain; while the flint and clay are used in the same proportions as in the first rule. If at any time the manufactory should not afford broken porcelain for the purpose, it is recommended that pieces be compounded, about a quarter of an inch thick, of the other three ingredients, wherein the proportions of gypsum and flint are augmented; and these pieces, having been previously converted into porcelain by baking, are to be ground and mixed in the above-mentioned proportions with the other ingredients.

It has of late years been the practice of some English manufacturers to use a considerable proportion of calcined bones, together with a small quantity of gypsum, in combination with china-clay, flint, Cornish stone and enamel. By this means porcelain of a brilliant and very transparent white is produced, which, however, is deficient in density, and very liable to crack on the application of hot liquids.

Several among the chemists and scientific manufacturers of porcelain in France have given recipes for the composition of tender porcelain, although this description of ware is no longer made in that country.

This kind of porcelain will support, without softening, a greater degree of heat than suffices to melt glass. It is semi-transparent, has a vitreous fracture, and returns a clear sound when struck by a hard body. It is harder but not so brittle as glass, and bears, without injury, sudden and very considerable alterations of temperature.

M. Brongniart recommends a mixture of one part of pure white clay, with three parts of a frit compounded of nitre soda, alum and selenite (sparry gypsum), together with a large proportion of ferruginous sand and a little common salt. The ingredients of this frit are to be calcined together, and the whole intimately kneaded; when cold, the compound is to be reduced to powder, and in that state mixed with the clay.

This paste is not so cohesive or viscous as that which forms hard porcelain, and greater carefulness is, therefore, called for in fashioning vessels with it. Lime and selenite, or any similar

earths which, if fused by themselves, produce a transparent and colorless glass, may answer the same purpose as the frit just mentioned. In making choice, however, of the compound to be thus used, it must be borne in mind, that the paste must not be more stubborn in resisting fire than the *seggars*, or vessels wherein it is inclosed during the baking, and no greater proportion of any substance that promotes fusion must he used than can be supported by the clay without having its cohesiveness greatly diminished.

The porcelain earth used in Berlin is compounded with silicious sand and sulphate of lime in crystals. The constituents of their flux are varied in the proportions according to the quality of the ware it is intended to produce. In the greater part of the German manufactories felspar is used, and some employ a calcareous sand.

When tender porcelain was made in the works at Sevres, a small portion of arsenic entered into its composition. This was found very hurtful to the workmen. Few of the turners or moulders, after following their employment for some years, escaped severe pulmonary complaints; and to this disadvantage is ascribed the order of the French government under which this branch of the manufacture has been discontinued in that establishment.

Individual manufacturers of porcelain in France avoid all the labor of preparing their materials, and purchase these in a state of readiness from establishments at Limoges where the best porcelain earth is found. The price of the compound, when delivered in Paris, or at an equal distance from the place of preparation, does not exceed three sous—about one penny halfpenny of our money—per pound.

This arrangement must considerably simplify the operations of the manufacturers, and lessens the amount of capital which they must employ in the establishment of their works; but it is doubtful whether the accompanying disadvantages are not fully equivalent to these benefits. There are many reasons to render such a plan ineligible in this country.

CHAP. IV.

ON THE FORMATION OF UTENSILS.

Throwing.—Potter's Lathe.—Thrower.—Mode of Proceeding.—Profiles.—Slurry.—Gauges.—Turning Lathe.—Turning and Smoothing.—Moulding Dishes, &c.—Tools.—Steam Machinery.—Engine-Lathe.—Milled Edges.—Handler.—Formation of Handles, Spouts, &c.—Pressing.—Small Ornamental Figures.—Mode of affixing them.—Method of making Moulds.—Boiled Plaster.—Great use of Gypsum in making Moulds.—Stoves.—Modelling.—Qualifications requisite for a Modeller.—Increasing Skill of Artists.—Fostered by Mr. Wedgwood.—Mould-Maker.—Method of his Working.—Casting.—Carefulness required in Drying.

THE operation of throwing consists in shaping such vessels as have a circular form, and is performed upon a machine called a potter's lathe.

This consists of an upright shaft, about the height of a common table, on the top of which is fixed a circular piece of wood, whose breadth is sufficient to support the widest vessel that is to be made. The bottom of the shaft runs in a step, and the upper part in a socket a little below the circular board, so that

Fig. 1.

the shaft and board turn together. The shaft has a pulley fixed upon it by means of which it is turned, an endless band passing round the pulley from a wheel placed at a short distance, and which is ten times the diameter of the pulley; this wheel when turned by a handle sets the lathe in motion.

The clay to be thrown is first cut and weighed and formed into a ball. It is then placed on the face of the circular board, which being put in motion, the *thrower*, dipping his hands from time to time into water, or slip, that the clay may not adhere to them, fashions it first into a long thin column, which he forces again down into a lump, and continues these operations until assured that no air-bubbles can possibly remain in the body of the clay. He then directs that the speed of the wheel shall be mode-

rated, and proceeds to give the first form to the vessel. This is done either by his fingers alone, or with the aid of an instrument shaped according to the desired form. The instruments employed for this purpose are called profiles or ribs. By the assistance of one of these, the inside is smoothed and made to assume the requisite shape, and any inequalities, technically called *slurry*, are removed. When it is wished to make any number of vessels exactly similar to each other in shape and dimensions, certain pegs are fixed as a gauge without the circumference of the revolving board, but placed in such a manner, that whenever the plastic clay is brought to coincide at the requisite points with the gauge, the thrower knows that the article has attained the proper dimensions.

In this manner most circular-shaped vessels are formed. When finished to the artist's satisfaction, he proceeds to remove his work, cutting it from the lathe by passing a thin brass wire through the lowest part of the clay. The vessel is then lifted off and placed on a board or shelf, where it is left to dry partially before it is farther smoothed and shaped in the *turning-lathe*.

When the vessel is so far dried as to be in that particular state of hardness well known to the workmen, and which is called the *green state*, it is in the most favorable circumstances for the performance of the remaining operations of turning and smoothing, for being furnished with handles, spouts, and such appendages as cannot be affixed in its first formation.

For making circular dishes, plates, saucers, or shallow bowls, and other vessels of that class, a plaster mould is used. This is slightly sprinkled with powdered porcelain, sifted through a fine cloth, and placed on the block which surmounts the upright spindle of the lathe. The block being then set in motion, the clay is fashioned in the first place by the hand of the workman, which presses it against the mould, and afterwards with a profile to give the requisite internal form. If any ledge or foot is required, it is affixed afterwards with slip, in the manner hereafter described as employed for joining handles and spouts. All superfluous parts are cut away, and the whole is finished by means of a horn tool and a damp sponge. When sufficiently dry to be taken from the moulds, the edges are pared with a sharp knife, and the pieces are slightly polished by the hand. After this, they are placed in piles of four, six, ten, or more, according to their weight and solidity, and are left to harden, preparatory to their being put in the oven.

The *turning-lathe* of the potter is similar to that used by the turner in wood. The end of the spindle has a screw thread, upon which are screwed *chucks* of wood, tapered in their form,

and differing in their diameters according to the size of the article to be turned. The tools employed are of different sizes, from a quarter of an inch to two inches broad, and six inches long: they are made of iron, the cutting end being turned up about a quarter of an inch, and ground to a good edge.

The vessel to be turned being fixed upon the chuck, and motion communicated to the lathe, the turner proceeds to reduce the substance of the clay in such parts as are required, to form rings and rims upon the vessel, and generally to attend to those little niceties of shape which are not easily attainable on the throwing-lathe. When this is completed, a contrary motion is given to the spindle, the turner applies the flat part of his tool to the vessel, and using a gentle pressure, produces the requisite smoothness of surface and solidity of texture.

In those considerable establishments which are furnished with a steam-engine, the throwing and turning lathes are both actuated by it. To the first of these machines motion is then given by means of two upright cones, placed opposite to each other; the apex of the one answering to the base of the other. One of these cones receives motion directly from the engine, and communicates it by means of a leather strap to the other. By this arrangement the horizontal strap has always an equal tension to whichever parts of the cones it is applied, the enlargement of the one answering to the diminishing diameter of the other; but the speed given to the lathe will depend upon the position on the driving cone which the strap occupies: if this is at the small part, the driven cone, and consequently the revolving-board of the lathe, will travel more slowly, and its revolutions will, on the other hand, be accelerated in proportion as the strap is made to occupy the larger part of the driving cone. When the strap takes its position on the largest part of this, it will apply to the smallest part of the driven cone, and the speed of the lathe will be at its maximum. The position of the strap upon the cone is regulated at pleasure by a winch, a boy in attendance upon which follows the directions of the thrower. When the article is finished, the strap is thrown off the driving cone, and the motion of the lathe of course ceases.

The turning lathes, when actuated by the steam-engine, are arranged in a row, the whole length of the room, through which runs a horizontal shaft, and this has fixed upon it, opposite to each lathe, a drum, straps on which connect the shaft with the lathes. The speed of the lathes is regulated by providing pulleys of different sizes, upon any one of which the strap may be guided by the turner during the revolutions of the spindle. When the turning of the vessel is finished, the strap is transferred to another pulley connected by a crossed strap

with the spindle, which by that means has a reversed motion communicated to it, and the article under operation is smoothed and polished in the manner already described.

A milled edge is given to earthenware in what is called an *engine lathe*, where, in addition to the rotary motion communicated to the article, it has likewise a horizontal movement to and fro, enabling the workman to make the requisite incisions at proper and definite intervals.

When the vessels are taken from the turning-lathe, they are delivered to the handler, who fixes upon them handles, spouts, and other appendages of that nature. These are affixed to the vessels by means of slip, with which the parts brought into contact are moistened. Being then left for a short time to dry, the junction is found to be perfect; and with a knife the superfluous clay is removed from about it: the whole vessel is next cleaned with a damp sponge, which moistens the whole equally, and gives uniformity to its appearance.

Handles, spouts, and objects of that nature are made with the aid of a press, consisting of a small metallic cylinder, which has an aperture in the centre of its bottom, to which plugs with differently shaped orifices are fitted. It has also a piston, actuated by a screw, which works through an iron bow attached to opposite sides of the cylinder. The aperture in the bottom being furnished with a plug of the desired form, and the cylinder charged with clay, the piston is inserted, and by the turning of the screw is forced down upon the clay, causing it to protrude through the aperture in the proper shape. This being cut into lengths, and bent into the required form, is, when sufficiently dry, affixed to the vessel as already mentioned. If the clay is required to take a hollow cylindrical form, as it must for spouts, a pin of the same diameter as it is wished to give the tube is fixed above the centre of the plug. It is obvious that some ornamented spouts cannot be made by this means. For forming such, two moulds of plaster must be prepared in the manner hereafter described, one half of the figure being impressed in each of the moulds, which must fit together accurately. Clay is then forced into each mould, and the superfluous quantity being cut away, leaving still a small portion above the level of the moulds, the two are brought firmly together to unite the two halves of the article. The mould is then divided, the clay is removed, and finished as to its form with suitable tools by the workman. This is the operation known under the name of *pressing*. The moulds for the purpose are made with plaster of Paris, (gypsum, or the native sulphate of lime,) the peculiar fitness of which material for the purposes, arises from its property of absorbing water with very great rapidity, so that the

ware inclosed within it speedily dries in a sufficient degree to *deliver* itself (according to the workman's phrase) easily from the mould.

Small ornaments, such as figures, animals, foliage, and the like, are more conveniently made by pressing the clay in plaster moulds, or otherwise these are made of copper, which must previously be slightly smeared with oil, in order to insure the easy delivery of the ornaments. These are then affixed to the vessel by means of slip, according to the method already described. It is in this manner that drinking jugs are so commonly ornamented with figures in relief.

In order to prepare the plaster for making moulds, it is first ground between a pair of stones, in a mill exactly similar to that employed for grinding wheat; it is next *boiled* in order to drive off the water which forms a considerable constituent part of its natural substance. There is an appearance of absurdity in thus speaking of boiling a dry earthy substance; but the workmen who use the term, are not very far wrong in their expression. To all appearance, ebullition goes rapidly on in this operation, and there is a disengagement of steam as in the boiling of watery fluids. When this process is completed, the substance is always called boiled plaster. The evaporation is conducted in long brick troughs, having a fire flue running under their entire length, in a manner similar to the slip-kiln. The man who superintends the process, is obliged to wear a handkerchief over his mouth and nostrils, to prevent the passage of any particles of the gypsum to his lungs, or stomach, such a circumstance having been found very prejudicial to health.

The plaster when thus deprived of its water becomes a soft impalpable powder, but when its natural proportion of water is again added, so strong is its affinity for that liquid, and such its capacity for again combining with itself that portion of which it has been deprived, that it attracts and condenses the whole, and will immediately set into a hard and very compact mass, peculiarly suitable for the purpose here required.

The consumption of plaster cf Paris, in making moulds for plates and dishes is so considerable, that in the district comprehending the Potteries, in Staffordshire, many tons are annually worn out and thrown away as useless.

Articles placed in these moulds part with moisture so rapidly, that when put in a very temperate stove, they will become dry enough for removal in two hours, and each individual mould is capable of being used for forming four or five different articles in the course of a working day of twelve hours. The stove wherein these moulds, with their contents, are placed to dry, is a small room built with bricks, and having wooden shelves

ranged round it, and over one another from the floor nearly to the ceiling; it is heated by warm air conducted through it in an iron pipe.

Moulds for producing simple wares, such as plates and dishes, and generally for such objects as are formed by pressing, are simple in their construction; but others, which are used for the third department, that of casting, call for much more art and skill for their invention and execution. For these, the taste of the *modeller* is put in requisition, calling for the exertion on his part, of a high degree of skill and ingenuity in forming patterns, and adapting to them appropriate ornaments. To be a perfect modeller, in the higher branches of the art, a man should have an acquaintance with the best productions of the classic climes of Greece and Rome; he should be master of a competent knowledge of the art of design; his fancy glowing with originality, tempered and guided by elegance and propriety of feeling, and restrained by correctness of taste and judgment. To a man thus gifted, the plastic and well-tempered material wherewith he works offers little of difficulty in the execution of his conceptions.

In the most considerable works, and where the proprietors are ambitious of excelling, modellers are kept in constant employment. Other manufacturers content themselves with buying new moulds from artists who compose them on speculation, and who are sometimes so little scrupulous as to dispose of the same pattern to several different purchasers.

For want of due encouragement, high degrees of excellence in this art were formerly not of frequent occurrence. Mr. Wedgwood, to whom the porcelain manufacture of England owes so many and such various benefits, proved that talent in this branch of art needed only for its development to be fostered and encouraged with liberality. This patriotic individual paid the sum of four hundred pounds to Mr. Webber for modelling the Portland or Barberini vase, although the work called for no original or inventive powers. Since that time, English modellers have attained to such a degree of excellence, that it is said any good modeller, with one qualified assistant, would be able to achieve, in the short space of two weeks, the task which occupied Mr. Webber for many months, and which was viewed, at the time, as an honorable proof of both his talent and industry.

The model, when moulded by the hand, must be trimmed, carved, touched, and retouched with suitable tools, constructed of metal or wood, and sometimes even of ivory, for the more perfect finishing of the whole composition.

When thus completed, the model passes into the hands of the

mould-maker, whose occupation is quite mechanical and distinct from that of the modeller. A strong casting of clay is first formed and securely fixed round the model, leaving sufficient space between for the substance of the mould. Proper proportions of plaster of Paris and water are then placed in a jug, and the mixture is briskly stirred, so that the water may thoroughly pervade the whole, which is then poured gently upon and around the model, covering it in every part to the requisite degree of thickness. Upon this some heat is sensibly given out by the plaster, and the whole is very shortly converted into a hard compact mass, easily separable from the model, and found to exhibit a perfect impression of its form, and the minutest niceties of its ornaments. The mould is, after this, placed in a stove to be thoroughly dried, and is then fit for use.

Many articles were formerly made by casting, which are now produced by the operation of pressing last described. Casting is now employed only for the formation of irregular-shaped vessels, where much nicety is required, and which need not have much strength. The casting operation is performed by intimately mixing the united clay and flint with very pure water to the consistence of cream. On pouring this dilution into the mould, the plaster quickly absorbs water from that portion which lies in contact with its surface, hardening it to such a degree, that on the central and still fluid part being poured off, a coating of clay will remain attached to the mould. This coating having been allowed further to dry during a short time, a second charge of diluted clay, but the consistence of which is much greater than the creamy fluid first used, is poured in, and adds to the substance of the first deposit. Having remained in the mould sufficiently long for this purpose, the remainder of the semi-fluid is poured off, and the mould, with its contents, is set in a stove: when sufficiently dry to allow of separation, the article is taken from the mould, and left until it is brought to the *green* state, when all imperfections are rectified by the workman, whose skill is exerted to render the vessel as smooth and as perfect as possible.

It is essential to the excellence of all kinds of earthenware, that the means used for drying it previous to the baking should produce an uniform evaporation throughout its entire substance. If too much heat were artificially employed, the surface might be hardened, while the internal part remained moist; and this would be attended with disastrous consequences in the oven, owing to the unequal contraction that would then ensue. It is, for this reason, necessary to allow time for the gradual dispersion of moisture, which, however, may be advantageously expedited,

by placing the pieces upon plaster shelves, whose absorbent property would occasion the requisite drying in a shorter time, and with increased regularity and uniformity.

CHAP. V.

ON THE PROCESSES OF FIRING AND GLAZING.

Seggars.—Proper Materials for these wanting in England.—Not so in France.—Nungarrow Work.—Why discontinued.—Great Estimation of its Wares.—Cause of Superiority.—Use of Seggars.—Their Forms.—Mode of using them.—Sevres Manufactory.—Improved Furnace.—Its advantages.—Description.—Chinese Method of Firing.—Construction of their Kilns.—Care required in Baking.—Duration of Process.—Oven-Man.—. Trial Pieces.—Annealing.—Biscuit.—Wine Coolers.—Glazing.—Composition of Raw Glazes.—Bad effects of some of these to the Public.—To the Workmen.—Pernicious use of Ardent Spirits.—Glazes invented by M. Chaptal.—By Mr. Rose.—Porcelain Glazes.—French Glazes.—Palissy.—His Experiments on Enamelling.—His Perseverance and Sufferings.—His Success, and continued Firmness under Persecution.—Inferior Glazes.—Low-priced Wares.—Gloss-Oven.—Regulation of Temperature.—Qualities that determine the Excellence of Porcelain.—Stone-Ware.—Its Composition.—Lambeth Potteries.—Modes of Glazing.

In the state whereto the vessels are now brought, they are ready to undergo the first application of fire in the oven. For this purpose they are placed in deep boxes called *seggars*, made of a mixture of fire clay and old ground seggars, which should be well baked, and capable of sustaining the most intense degree of heat without being fused. The porcelain manufactures of this country labor under a considerable disadvantage in this respect, being unable to procure materials for the construction of these cases that will sufficiently withstand the direct heat of the furnace. This difficulty does not occur in France, a fact which is assigned by our potters as one principal reason for the better quality of French porcelain.

A porcelain manufactory was carried on some years since at Nungarrow in Wales, but which is now discontinued. The wares produced in these works were perhaps superior in quality to any porcelain that hitherto has been made in any other part of this country. No expense was spared either in the procurement of materials, or in conducting the various processes; and the want of success on the part of the spirited proprietors is referrible solely to the deficiency of public patronage, it being found impossible to procure a price for the goods which could adequately meet the cost of their manufacture. Since the discontinuance of this establishment, the excellent quality of its wares has been more justly estimated, and the prices which are now eagerly given by amateurs and collectors for pieces

of Nungarrow porcelain, are out of all proportion greater than were originally demanded by the makers.

The materials of which this porcelain is composed are of the most refractory quality, and it is understood that success in their conversion was only attained through the expensive measure of sacrificing the seggars employed, which, owing to the high degree of heat whereto they were exposed, could never be placed a second time in the furnace.

The office of the seggars is to protect the wares while being baked from the direct application of flame and from smoke; the heat is somewhat modified in its transmission through them, and applies itself uniformly to each part of the vessels. The cases are made of various shapes, sizes, and depths, to suit the different pieces they are to contain, and some judgment is required in their composition, to fit them for the several kinds of pottery.

To prevent any adhesion of the pieces to the seggars, the flat bottom of each is covered with a thin layer of fine white sand. That this even may not adhere to the porcelain, the Chinese strew over the sand some dry kao-lin in powder. Pieces of any considerable size must each be inclosed in a separate case, but smaller objects, such as cups or saucers, may be placed together to the number of six or twelve, but in no case must one piece be placed in or on another in the seggar, and all must be so arranged that the heat will be equally applied to every part of each.

In some instances seggars are made having triangular holes in their sides, for the purpose of admitting prisms of the same form, which are inserted therein, horizontally, in order to support a greater number of pieces in a state of isolation within each case than could be accomplished by other means. The prisms thus used must be compounded of the same materials as the cases themselves. This course is not pursued except with common articles, and is adopted with the intention of economizing the time, space, and fuel employed for baking them.

If the clay whereof they are composed be well chosen and carefully managed, the seggars may be placed from fifteen to twenty several times in the furnace before they are rendered useless.

Some art is required so to dispose the cases within the oven, with reference to their shape, size, and the objects they contain, that the heat shall be distributed as faithfully as possible, and that the sufficient baking of all the different-sized vessels shall be accomplished during the same time. The largest and coarsest pieces are usually placed on the floor of the oven, which must be previously covered with a layer of sand. If the

heat be not faithfully distributed through the whole area some pieces would be injured by excessive firing, while others would be inadequately baked. The bottoms of the seggars being flat, each, as it is placed upon another, forms a cover to that beneath, and the entrance of smoke is further prevented by placing a ring of soft clay on the upper rim of each case. In this manner the seggars are built one upon another, until they reach nearly to the top of the oven: the upper seggar in each pile is always empty. Each of these piles, as it stands, is called a *bung;* in building them up, intermediate spaces of about three inches must be left for the circulation of heated air throughout.

Although the privileges so long enjoyed by the royal manufactory at Sevres, and which were accompanied by corresponding restrictions placed by the French government upon private establishments, must have been upon the whole prejudicial to the progress of the art in France, these regulations had yet in some respects a contrary tendency. Being secured in a great degree from the effects of competition from without, the directors of the royal works were enabled to prosecute experiments with regard to improvements in their utensils and processes, from the adoption of which they might otherwise have been deterred by considerations of expense. Suggestions appear to have been continually made, having such improvements for their object, by men who enjoyed the highest scientific reputations; and the success of plans thus proposed, conduced to the increasing celebrity of the establishment.

Among others, MM. de Montigny and Macquer contrived a form of furnace, which effected at the time of its adoption a very great advantage. In that previously used (and the construction of which had been copied from those employed in Saxony,) the heat was so unequally distributed, that it was necessary to vary the composition of the porcelain so as to render it suitable to different parts of the furnace. The improvement here noticed occasioned the sufficient equalization of heat throughout its area, and a great inconvenience was at once and completely remedied.

The arrangement whereby this important change was accomplished will be understood by a reference to the following figures, which describe the elevation, section, and plan of the kiln. The same letters are employed to denote similar parts in the different figures.

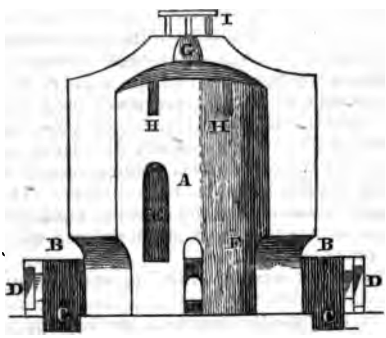
A is the interior area of the kiln. This is fourteen feet eight inches high, and eight feet three inches in diameter: the walls should be three feet thick. BBBB are four air-flues placed at equal distances in the circumference. CCCC are

hearths one foot below the base of the kiln: the heat from these passes towards its centre. DDDD are openings, eighteen inches square, for the reception of the fuel. These open-

Fig. 2.

ings are provided with mouth pieces of plate iron. E is a door-way in the side of the kiln: its sill is three feet above the

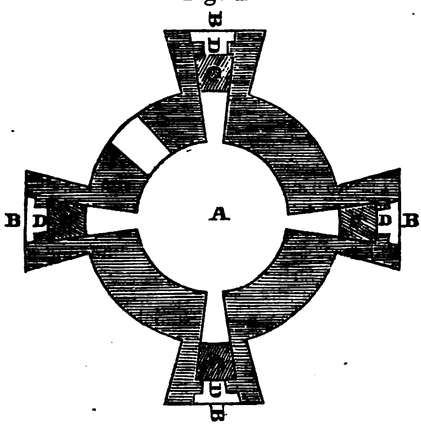
Fig. 3.



ground; its width is two feet, and its height five feet six inches. This door is used for the introduction of the seggars within the kiln, after which it must be securely walled up. F is a square hole, of which there are three in the entire circumference. These are designed for the introduction of trial pieces within the kiln: another similar opening is left when

walling up the door-way E. The whole of these are provided with clay stoppers which exactly fill the holes, and which have projections whereby they can be removed or replaced at pleasure. G is the chimney in the centre of the dome-shaped roof; it is of a conical form, eighteen inches diameter at the base, lessening to twelve inches at the top. H H represent four air-

Fig. 4.



holes, placed over the openings F. These air-holes serve to divide the draught, and consequently to equalize the temperature of the kiln. I is a round iron plate, supported on four pillars of the same metal, and placed over the chimney to defend the opening.

When the firing has been sufficiently performed, no more fuel is added, and so soon as the smoke from that already upon the hearths has passed away, the mouth pieces are entirely closed to prevent the passage of air. Shortly after this, the chimney G and the air-holes H are also carefully closed, and the kiln is left, that the cooling of its contents may go forward as slowly as possible.

Previously to the adoption of this improvement, the kiln employed for baking porcelain was always made of a rectangular form, having only one fire-place and one air-flue, which stood at the side opposite to that whereon the chimney was placed: an arrangement which rendered quite inevitable the before-mentioned inconvenience, arising from the unequal distribution of heat.

Enamel is glass made opaque by the oxide of tin, and rendered fusible by the oxide of lead. All glazes that contain lead participate in the properties of enamel. Raw glazes used for covering tender porcelain are of this nature. The colors employed in painting this porcelain are those which serve for painting in enamel; they require less flux than others, because the surface to which they are applied becomes soft enough to be penetrated by them. Hard porcelain, whose nature is identical with those of China and Saxony, has two kinds of colors applied to it. Those of the first kind, which are used in the representation of different objects, are baked in a heat much below that necessary for baking porcelain; while the other colors, which are few in number, must be exposed to the highest degree required by the porcelain itself. The glaze used for hard porcelain has little or no lead in its composition. The Sèvres manufacturers, and some few in England, employ felspar without any mixture of lead. This glaze, when exposed to the heat of the gloss oven, dilates, and its pores are opened without becoming soft, so that the colors are not absorbed by it, and do not undergo those changes which occur when they are applied to tender porcelain, where, by mixing with the body of the enamel, they become faint and indistinct. This effect is much increased likewise where some particular colors are employed, and especially the reds produced from iron, which are exposed to the destructive action of the oxide of lead that is contained in the glaze. Painting on tender porcelain must, for these reasons, be several times retouched with the pencil, in order to give to it the distinctness and brilliancy which follow the use of the same colors on hard porcelain, so that a high degree of ornament is seldom or never given to any but the latter description. In the embellishment of hard porcelain, these retouchings are not required, except for the most elaborate specimens of the art, which can by such means, however, be produced with the most admirable degree of perfection, so as to render paintings on porcelain not distinguishable from the finest productions of the pictorial art, without reference to the body upon which it is performed, or to the means used for bringing out the colors; natural objects, landscapes, portraits, and even historical pieces being represented with all the truth, as well as with all the brilliancy of coloring, which distinguish the works of the first masters.

One great inconvenience attends the repeated exposure to the heat of the oven of pieces thus retouched; the colors being liable to peel off, unless the greatest care has been used in their application. This defect has been remedied in the Sèvres works, by introducing a calcareous flux into the felspar glaze,

which softens it, without at all affecting the body of the ware. Soda and potash are never used as fluxes, as their introduction causes the colors to scale; the reason for which is, that, becoming volatile in a great heat, they abandon the color, which then will not adhere to the glaze.

The liquid matter which serves as a vehicle in laying on the colors, is rubbed with them upon a glass palette until the whole is intimately united. The mixture must be brought to that state of dilution which is most proper and convenient for its application with a hair pencil on the surface of the porcelain. Great care is used in the choice and management of these diluent liquids, which must always be sufficiently volatile to be entirely dissipated in the heat to which the wares are afterwards exposed. In France, the preference is given to oil of lavender as a vehicle; and in order to insure the proper degree of fluidity, this oil is divided by distillation into two parts: that which first comes over, being the most volatile, and having the least density, is used for diluting the colors when they become too thick; and, on the other hand, the portion that remains in the retort, having the opposite qualities, is reserved for thickening them when they run too freely. Oil of turpentine, which has been some time in store, is more generally used in England, and is said to answer the purpose better than any other volatile fluid.

It was remarked by Brongniart, whose practical knowledge qualified him to judge correctly on the subject, that of all the processes for painting on glass and porcelain described in works that were in existence at the time his essay was published, there was not one, by strictly following which, the desired colors could be produced. In describing these processes, one author had followed another without knowledge or examination; and even the treatise by Leviel, which forms part of the voluminous work on arts and manufactures, published under the auspices of the Academy of Sciences in Paris, is not free from this reproach. Such want of correctness, from whatever cause it may have arisen, is little honorable to the authors, who if even unable, by penetrating the veil of mystery wherein the manufacturers shrouded their practices, to expose them correctly to the world, might, without difficulty, have ascertained the truth or falsehood of that to which they were affixing the stamp of their authority. The course which they pursued would assuredly fail of success in the present day, when an acquaintance with chemical phenomena is no longer confined, as it formerly was, to a few among the rarer order of students, and such errors would be certain of confutation at the moment of their promulgation.

Purple and *violet* colors are procured by dissolving gold in aqua regia (nitro-muriatic acid), and immersing a bar of pure tin in the solution. The product thus obtained is called, from its inventor, the purple precipitate of Cassius, and is used very generally for giving the above-mentioned colors to porcelain. A preferable way of preparing this precipitate is to dissolve the two metals separately, and by then bringing the solutions together in different proportions, various shades of carmine, violet, and purple are obtained. The first of these three tints is seldom used in porcelain works, for although extremely beautiful, it is also very transient, and may be easily spoilt by a small excess of heat, or by the contact of carbonaceous vapors, a circumstance which is the less important, as its place may be well supplied by a rose color obtained from iron, and which is not liable to the same disadvantage. Carmine color, when used for tender porcelain, is prepared with fulminating gold (made by dissolving the metal with aqua regia and precipitating with ammonia), and muriate of silver. This compound is without any addition of tin, which shows that an union of the oxide of tin with that of gold is not necessary—as many have supposed—for the production of purple.

Violet color is also made with the purple oxide of gold, requiring the presence of some portion of lead in the flux for the development of this shade. These three colors cannot bear exposure to the full heat of a porcelain furnace, in which they would wholly disappear. In using the precipitate of gold, it is mixed with about six times its own weight of flux, and is employed without previously fusing the two bodies together. When first applied on the porcelain, it is of a dirty violet color, but by exposure to heat this passes to a most beautiful purple. It is recommended to employ charcoal as fuel in baking this color. Frequent exposure to the fire will materially impair its beauty.

Red oxide of iron, prepared by the united action of fire and nitric acid (the aquafortis of commerce) yields a *red* color, which, although beautiful, is less brilliant than that produced from gold. As already stated, it is, however, preferable on account of its less liability to change. Shades of red, deepening from rose color, and passing by the increased application of heat to brown, are obtained from iron. The flux employed with this oxide is composed of vitrified borax, sand, and a small proportion of red lead, and the color may be used either with or without previous fusion with its flux. By the mixture of black and red oxides of iron, in different proportions, various shades of reddish brown, chestnut, &c. are obtained. Red colors produced from iron cannot be used on tender porcelain, since they

disappear, in that case, on exposure to heat. This effect must be ascribed to the presence of lead in the glaze. Several experiments, conducted by M. Brongniart, have proved this fact beyond all controversy.

A very permanent red color is procured by calcining the oxide of iron with double its own weight of common salt (chloride of sodium). The processes used for this purpose must be carefully conducted, and the salt purified and decrepitated—that is, subjected to the action of heat until all crackling noise has ceased. The oxide is procured by dissolving iron filings in nitric acid, and precipitating with salt of tartar (subcarbonate of potass). The precipitate must then be placed on a thin sheet of iron, and exposed under a muffle to the heat of a charcoal fire, until it has taken a fine red color. The two substances having been well triturated together in a glass or porcelain mortar, are then calcined in a crucible, and the operation should be carried as far as possible, without occasioning the vitrification of the mass. When taken from the fire and cooled, the compound is again triturated; successive portions of hot water are poured upon it, stirred, and then removed, until the water is no longer colored. The fluid thus tinged, is allowed to settle, and is, when clear, poured from the sediment, which is then washed five or six times in fresh portions of clear water.

To obtain *yellow* colors, for both hard and tender porcelain, white oxide of antimony, mixed with sand and oxide of lead, are employed, the latter substance serving as a flux to the others. Great carefulness is required in the preparation, as the lead frequently approaches, by reason of the heat, to a metallic state, and, in that case, appears in the form of black spots on the wares. Oxide of tin is sometimes added, and when the color is required to be livelier, and approaching to that of saffron, red oxide of iron is added, the too great redness of this being subdued by the action of the lead, in the fusion which the ingredients undergo, previous to their application on the porcelain. The colors thus produced are not susceptible of change, but if exposed to the full heat of a porcelain furnace would be entirely dissipated.

Oxide of uranium, mixed with oxide of lead, produces a straw color. By decomposing chromate of potass, with nitrate of lead, which is a saturated solution of lead in nitric acid, chromate of lead is precipitated, and this proves a very excellent yellow color.

Naples yellow is composed of 24 parts of ceruse, 4 parts of oxide of antimony, and one part each of alum and sal ammoniac (muriate of ammonia), calcined together at a moderate heat

during three hours. The shade is varied by increasing or diminishing the proportion of sal ammoniac. The quantity of flux that must be combined with this color for use is uncertain, and must be matter for experiment with the manufacturer.

For the production of *blue*, well prepared and very pure oxide of cobalt is employed, mixed with a flux. Oxides of tin and of zinc, added in different proportions, give different shades, from a deep rich color to a light blue. As the oxide of cobalt is volatilized at a high heat, it is impossible to place in the same case, white pieces, and such as are painted blue; since the former would certainly assume a bluish tint in the operation of baking. This difficulty does not occur with tender porcelain, on which the cobalt is not volatilized as in the other case, owing to the heat being very inferior to that used in baking hard porcelain. These blue colors, if they have been previously fused, do not change at all after their application. The rich smalt, known under the name of azure-blue, is only the glass of cobalt, mixed with sand. This color must be fused in a crucible, and reduced to an impalpable powder in an agate mortar, after which it may be used in combination with flux.

Prussian blue, which results from the union of hydrocyanic acid with oxide of iron, is very extensively used in the arts; and being prepared on a large scale for sale, in various parts of the kingdom, no manufacturer of porcelain will undergo the trouble, or encounter the unpleasant circumstances attendant upon its preparation, but will rather obtain the comparatively small quantity he may require by purchase.

Green oxide of copper is usually employed for the production of a green color. On precipitating in different vessels, by means of potass, solutions of copper which are equally pure and concentrated, it is perceptible that the precipitate is formed more quickly in some vessels than in others; and if these different products are separately collected, those which are most promptly formed are, when dried, of a fine bright green, and produce a corresponding color on porcelain; while those precipitates which are deposited more slowly, form earthy and less dense particles of a much darker hue, and which, when applied to porcelain, yield a less pleasing color, and pass sometimes to black during the baking. If, however, the precipitated oxide is previously fused with its flux, this change need not be apprehended. Very pure oxide of copper is frequently procured by placing sheets of the metal in the oven wherein the ware is glazed. Mixtures of yellow and blue are sometimes used in the composition of green colors: some of these will not exist in the heat of a porcelain furnace. Various shades of beautiful green may be obtained, by mixing, in different proportions, Prussian blue

with the chromate of lead already described. A mixture of the oxides of cobalt and nickel, will resist a very intense heat, but does not produce a genuine green: it is rather an olive color.

Oxide of chromium gives a beautiful green color, which is indestructible in the heat of a porcelain furnace. That class of green colors, called celestial blues, can only be applied, according to Brongniart, on tender wares: being partly composed of potass, they scale off from hard porcelain.

Different shades of light and of deep rich brown are obtained from mixtures of the oxides of iron. These must be fused with thin flux before they are used, after which fusion they do not undergo any change on the application of heat. Russet grounds, known under the designation of tortoise-shell, are produced in this manner. Felspar is employed as a flux with these colors.

There is not any metallic oxide which alone will give a good black. Oxide of manganese approaches the nearest to it. The black oxide of iron yields a very dull color, which sometimes changes to red. The color-makers therefore unite several oxides together, and thence obtain a very beautiful black. The oxides thus combined are of manganese, the brown oxide of copper, and a small proportion of the oxide of cobalt. A gray color is obtained by omitting the copper, and increasing the proportionate quantity of the flux.

Cobalt, oxide of copper, and umber, in equal parts, reduced together to an impalpable powder in an agate mortar, prove a very good black. This must be used with three times its weight of flux. Another black is composed of four parts oxide of copper, one part of smalt, and one part of black oxide of iron, which, like the former compound, must be rubbed together to a fine powder, and used with three parts of flux.

In the "Annales de Chimie et de Physique," (Vol. 20. 1822), directions are given for the preparation of a beautiful black enamel, the verification of which on the part of our porcelain manufacturers is perhaps desirable. The experiment necessary for this purpose might have been somewhat simplified, if the artist by whom the directions are communicated had stated the proportions wherein the ingredients should be brought together. The formula directs that chloride of platina, dissolved in water, should be mixed with nitrate of mercury. By then subjecting the precipitate which will be formed to a heat just sufficient to volatilize the proto-chloride of mercury, a black powder will be obtained. This is the enamel, which must be applied in the usual manner, in combination with a fluxing material.

M. de Montamy in his treatise, to which allusion has already been made, gives a *recipe* for composing a pure white color,

which is found very serviceable by the French artists in forming their series of shades, as well as in the composition of those parts of their designs which require to be represented in a brilliant white. This color is composed of one part of virgin tin, and two parts of common salt. The latter must be thoroughly purified, by first dissolving it in distilled water, then filtering the solution through paper, and afterwards evaporating it to dryness over the fire in a porcelain capsule. The salt, which is, by this means, made extremely white, must be further exposed to heat in a crucible, until all decrepitating noise has ceased. The purification will be yet more perfect, if, after filtering it, the solution is partially evaporated, and then placed in a cool situation to crystallize slowly. Those artists who are the most particular in their processes, select preferably from the rest such crystals as take the form of cubes. The next part of the process is to place a crucible on the fire, well covered, to prevent the entrance of smoke or ashes. When this crucible is at a red heat, the tin is introduced, and is left until it is not only fused, but red-hot, at which time the purified salt is added in the proportion already mentioned. Taking then a clean iron spatula, the end of which must be previously heated, the mixture is stirred until the substances are well incorporated together. The crucible being then again covered, is to be surrounded with burning charcoal, and from time to time, the spatula, which must be always perfectly clean and hot, should be introduced to agitate the mass. When the end of this spatula, in being tempered by the heat of the crucible, begins to grow white, it is a sign that the calcination is carried sufficiently far, and that the crucible should be removed from the fire; the calcination usually occupies an hour for its completion. The compound should next be bruised in a mortar of glass or of agate, and again placed in a crucible which is set in the midst of burning coals and covered with a muffle. The heat is then raised gradually, and continued during three hours, when, on removing the crucible from the fire, the color is found to be hard, and requires some force to detach it from the vessel. This done, it must be pounded in a mortar, and washed in hot water that has been filtered or distilled, and fresh portions of water added, until the fluid has no longer any taste of salt. The white color is afterwards to be boiled violently with an abundance of water in an earthenware vessel for two hours, supplying hot water during that time to replace the portion that is evaporated. When the supernatant water has become clear by standing, it must be poured off carefully.

This white may be advantageously employed in painting with oil, as it mixes well with it. When used on porcelain, it must

be mixed with three times its weight of flux. The preparation of this color will not succeed unless the tin is extremely pure, and it is essential that the nicest possible degree of cleanliness should be observed throughout the operations.

By making different mixtures of the various colors here described, every hue that can be desired may be obtained. It is not, however, so easy, as without due consideration it might appear, to produce these various shades. Great judgment in the selection of materials, carefulness in their preparation, and knowledge as to the relative proportions wherein they should be brought together, are essential to success; and an acquaintance with the science of chemistry is highly desirable. There are some colors which, if mixed, would mutually destroy each other, and on the exposure of metallic oxides to heat, changes ensue, which result not from the nature and habitudes of the colors themselves, but rather from the influence of the bodies to which they are applied.

It would be scarcely possible to treat satisfactorily upon the inciting causes of all these variations, a full knowledge of which can result alone from the practical experience of the artist and manufacturer.

Many potters do not prepare their own enamel colors, but purchase what they require from persons who manufacture them for sale. Some of these preparations are exceeding costly, and as the temptation to adulterate them is consequently great, the potter should have good reason to rely on the probity of the color-maker with whom he deals. A fraudulent mixture, the detection of which would be impossible before its use, except by means of a chemical analysis, might be the occasion, in its results, of severe loss and disappointment. With the exception of the great works at Sèvres, this system of purchasing their enamel colors has, for many years past, been very general among the potters of France. In a report made to the French government, by a commission appointed in 1819, to examine into the progress of manufacturing industry in that country, occasion was taken for offering congratulations upon this establishment of an independent occupation, as marking the great extension of the porcelain manufacture, and as offering to the artist means of obtaining every shade of color, prepared by persons whose interest is involved in ascertaining their effects when submitted to the heat of the furnace, thus removing all uncertainty from the operations of the painter, and rendering it unnecessary for him to suspend his work that he may prepare his colors.

The gold used in gilding porcelain is applied in a metallic state. To prepare it for this purpose, it is dissolved in aqua

regia, and the acid being afterwards dissipated by the application of heat, the gold remains in the state of powder at the bottom of the vessel. This powder must be mixed with borax and gum-water, as a vehicle for causing it to flow from the pencil and fix upon the wares; which being then baked, the gilding appears void of lustre, and requires to be afterwards burnished with either agate or blood-stone.

Gold and silver *lustre-ware* is commonly of an inferior quality. The metallic oxides used for covering these vessels are intimately mixed with some essential oil, and then brushed entirely over their surfaces. The heat of the enamelling oven, which dissipates the oxygen, restores the oxides to their metallic state, but with some diminution of brilliancy. The oxide of platinum is used for making silver-lustre.

Colors, when they are required for use, should be first pounded quickly in a mortar made of either agate, porcelain, or glass, with a pestle of the same material, and covered to prevent the access of dust. They must be afterwards ground on a glazed palette, firmly bedded in plaster on a wooden frame, and perfectly level. The artist who decorates porcelain is required to rub his colors with as much nicety as is used by miniature painters, so that there must not remain the least perceptible roughness, either under the muller or between the fingers. The requisite proportions of volatile oil and of flux are added and ground with the colors on the palette, the whole having been carefully weighed before their union. The general rule is tc put five parts of flux to two parts of coloring matter: but some colors, as already mentioned, require more, while with others this proportion would be too great. Smalt requires to have combined with it only half the sum of its own weight.

The artist must be attentive to grind his colors with the smallest quantity of oil that will suffice; if this should be in excess, it may in evaporating leave spaces between the particles of color, and the subject would appear very imperfectly executed. The fluidity of the mixture should be kept at that exact point which enables the artist to produce the finest strokes with clearness and facility.

Before the pieces which have been painted are baked in the enamelling-kiln, it is necessary to dry the colors by evaporating the oil used with them as the vehicle.

Every considerable pottery has enamelling-kilns of various sizes. These are in form like a chemist's muffle, from about six to ten feet long, and from three to five feet wide. The articles are piled in the kiln until it is filled, when the mouth being closed, fire is applied, and continued for about eight or ten hours, at the end of which time the colors are found to be burnt

into the glaze. In piling the pieces in the kiln, care must be used to avoid the placing of any one piece upon the gilt border of another. The muffle is provided with trial pieces, which can be extracted from time to time during the baking, and which will indicate the general state of the contents of the kiln, so as to govern the continuance of the operation. No delay should occur between the sufficient baking of the colors, and the withdrawing of the fire, as their brilliancy would be injured by its longer continuance. The contents of the kiln are left undisturbed until they are cool, and are then withdrawn. All impure exhalations are prejudicial to the beauty of colors, and every substance whence they can arise should, as far as possible, be kept away from the kiln during the process.

Gilding on porcelain or on glass is performed either with or without the addition of a fluxing material, the gold being made to adhere to the surface by the incipient fusion of either the glazing on the porcelain, or of the surface of the glass, or of the flux employed.

Gold is used for this purpose sometimes in the form of leaf gold, and at other times in that of powder, prepared either mechanically, or by chemical precipitation. When the first of these two methods is employed, leaf gold must be ground with honey or with gum-water of an equal consistence; the honey or gum being afterwards washed away, the gold may be kept for use in paper or in shells, and the use of these latter recipients has occasioned this powder to be known among artists as "shell gold." This precious metal is precipitated from its solution in aqua regia, by adding to it a watery dilution of green vitriol (proto-sulphate of iron) or strips of metallic copper. Gold powder may likewise be obtained from the same solution by distilling it to dryness; but this process is not so convenient as precipitation. The powder has also been procured by first forming an amalgam of the metal with mercury, and then evaporating the latter; but besides being expensive, the fumes of mercury are found to be extremely prejudicial to the health of the operators.

When gold powder is used, it must be mixed with gum-water as a vehicle. Where it is intended to apply leaf gold without any fluxing material to the body of the wares, these should be moistened in the requisite parts with a weak solution of gum-arabic, which must afterwards be allowed to dry. When the gold is applied, the porcelain or glass may be made sufficiently adhesive by breathing on it. If a flux is employed, it should, after being rubbed very fine with a muller, be diluted with weak gum-water, and very thinly spread over the parts which it is designed to ornament; when very nearly dry, the leaf gold is laid upon it.

Japanners' gold size, moistened to the requisite degree with oil of turpentine, is sometimes employed. Waiting then until the size is so far dried as to be only clammy to the touch, the gold leaf is laid on with cotton wool. As soon as the gold is applied, the ware is placed in an oven or muffle, that it may be burnt on.

Some old authors direct the artist to fuse gold with regulus of antimony, to pulverize the mass, and to spread the powder upon the parts to be gilded, exposing the ware afterwards to such a heat as will suffice to evaporate the antimony, while the gold remains fixed. This method of proceeding is objectionable, from the almost impossibility of spreading the powder in a sufficiently uniform manner, besides which, part of the gold will also be carried off, and some descriptions of glass are even fusible with the degree of heat necessary for perfecting the process.

Circular gold lines are frequently described on small articles, such as cups, saucers, and plates. To assist him in tracing these with accuracy, the artist employs a portable horizontal wheel, the height of which may be adjusted at pleasure, according as the nature of the work requires it to be performed in a standing or a sitting posture. The lower part of this wheel is somewhat similar to the leg and feet of a claw table, the leg being bored out for the reception of a stout metallic wire, the altitude of which is regulated by means of a thumb-screw.

The upper or movable part of the wheel has a like tubular cavity in its vertical part, by means of which it is dropt on to the upright wire, and is made to rest upon a shoulder fixed on the wire, so that the wheel may be made to turn truly upon this as its axis: the whole is surmounted by a horizontal table.

In proceeding to use this machine, the artist places his feet firmly upon the base of the wheel, and fixing the article to be ornamented upon the table, he causes the revolution of the wheel with his left hand, and holding his brush steadily in the other, describes the circles with the utmost facility and accuracy.

Burnishing, which is the last process performed in the manufacture of ornamented porcelain, is usually intrusted to female hands. The implements required for this purpose are, a burnisher of agate or blood-stone, some white lead, a piece of sheepskin for wiping the ware, and some vinegar. As extreme cleanliness is indispensable, the person engaged in burnishing does not even touch either the porcelain or her implements, but interposes between them and her hands a piece of clean white linen. The agate burnisher should be applied lightly on the gilding, following all the ornaments, and never rubbing in cross directions, lest the gilding should appear scratched.

After having rubbed the gilding for some time, a little vinegar or white lead should be applied to cleanse the surface. This being removed with a soft linen rag, the burnishing is recommenced, and continued until the gilding throughout assumes a satisfactory appearance.

It will be remembered, that in the preceding description of the colors used in painting porcelain, several were mentioned as being unable to support the heat of the gloss-oven. Others, however, have not this disadvantage, and will bear the highest temperature without injury. Where colors are applied directly on the biscuit, no oil is ever ground with them, but they are mixed with water only, and the glaze may be added without any intervening application of heat. The temperature of the enamel-kiln is usually about six degrees of Wedgwood's pyrometer, answering to 1857 degrees of Fahrenheit's scale.

In the year 1817, the Society for the Encouragement of Arts, &c., awarded a premium to Mr. R. Wynn, for a list of receipts communicated by him, for the preparation of enamel colors and fluxes. A copy of Mr. Wynn's paper is inserted in the 35th volume of the Transactions of that Society.

The fluxes are,	No. 1.	Red lead	8 parts.
		Calcined borax . .	$1\frac{1}{2}$
		Flint powder . . .	2
		Flint glass	6
	No. 2.	Flint glass	10
		White arsenic . . .	1
		Nitre	1
	No. 3.	Red lead	1
		Flint glass	3
	No. 4.	Red lead	$9\frac{1}{2}$
		Borax, not calcined	$5\frac{1}{2}$
		Flint glass	8
	No. 5.	Flint glass	6
		Flux, No. 2.	4
		Red lead	8

The ingredients forming each of these fluxes are melted together, and the compounds are then finely pounded for use.

The recipes for colors are as follows:—

Yellow.	Red lead	8 parts.
	Oxide of antimony	1
	White oxide of tin	1

Mix the ingredients well in a biscuit-ware mortar, and having put them on a piece of Dutch tile in the muffle, make it gradually red-hot, and suffer it to cool. Take of this mixture 1 part; of flux, No. 4, $1\frac{1}{2}$. Grind them in water for use. By varying

the proportion of red-lead and antimony, different shades of color may be obtained.

Orange.	Red lead	12 parts.
	Red sulphate of iron . . .	1
	Oxide of antimony	4
	Flint powder	3

after calcining these without melting, fuse one part of the compound with 2½ parts of flux.

Dark-red.	Sulphate of iron, calcined dark . .	1 part.
	Flux, No. 4. . 6 parts } Colcothar . . 1 } of this . .	3
Light-red.	Red sulphate of iron, . .	1 part.
	Flux, No. 1.	3
	White lead	1½
Brown.	Manganese	2¼
	Red lead	8½
	Flint powder	4

The style of decoration described in the preceding pages of this chapter, is in a great measure confined to the most costly descriptions of porcelain. Wares which are fitted by their price for being brought into more general use, undergo a different kind of embellishment. A great variety of neatly executed patterns are transferred to their surfaces from impressions previously printed on paper. Before the introduction of this style of ornament, table services of home manufacture were either composed of plain Queen's-ware, with occasionally a colored edge; or at best were furnished with a painted border, which displayed but little taste in its conception, or ability in its execution. This modern improvement has added materially to the decent comforts of the middle classes in England, and has more than any other circumstance contributed to the great extension of our trade in earthenware with the continent of Europe. When first invented, and for some time afterwards, the designs employed were only imitations of figures and objects seen on old blue China porcelain; but a better taste has since prevailed, and artists employed in the composition of patterns no longer think it necessary to outrage truth in their representations. Landscapes and figures, in conformity with the simplicity of nature, and exhibiting a considerable degree of taste, are now so common, that this new advantage derived from the printing-press is enjoyed without exciting attention or commanding acknowledgment.

The method of transferring printed designs to earthern vessels is thus pursued. The landscape or pattern is engraved upon copper, and the color, which is mixed with boiled linseed oil, is laid on the plate in the same manner as ink is usually

applied by copper-plate printers. To increase the fluidity of the oil, the plate is then temporarily placed in a stove, a sheet of damped tissue paper is laid on it, and both are passed in the ordinary manner through the press. The paper, wet with the color, is then delivered to a girl, who reduces its size by cutting away the blank portion surrounding the pattern, and passes it to another girl, by whom the impression is applied lightly to the ware when in the state of biscuit. A third girl is next employed, who, with a piece of woollen cloth rolled tightly in the form of a cylinder, rubs the paper closely against the piece, in order to press the color sufficiently into its substance. The paper thus rubbed is left adhering to the article for an hour, when both are placed in a cistern of water, so that the paper becomes soft enough to be peeled off without violence, having transferred to the biscuit the impression which it had received from the copper-plate.

When the pieces thus printed have stood a sufficiently long time to become dry, they are placed in an oven, to which a gentle heat is applied, in order, by dissipating the oil, to prepare the wares for receiving the glaze. This is, of course, completely transparent, as otherwise the distinctness of the pattern would be impaired.

For a long time blue, produced from the oxide of cobalt, was the only color employed; but, of late, the potters have extended to this pleasing branch of their art all the colors on their palette.

The glaze on printed goods is vitrified in the gloss-oven in the manner already described.

The French potters employ a different method for transferring engraved patterns. They cast a sheet of fine glue, about a quarter of an inch thick, and diluted while warm to such a degree that when cool it shall be perfectly flexible, and have the consistence of leather. This glue being applied upon the plate, and pressed with the hand, receives the colors according to the pattern, which it gives back to the surface of any vessel to which it may be applied. Two impressions may generally be given in this manner without a fresh application of the glue to the plate. After the second has been impressed, the surface of the glue is cleaned carefully with water applied by a soft brush, and serves again as before.

The decoration of earthenware by means of engravings is of much more recent adoption in France than in England,—not having been used in the former country until about the year 1805.

In the report made by the Committee appointed to examine into the progress of the arts and manufactures in France, as

exemplified by specimens exhibited at the Louvre in 1819, and to which report allusion has already been made in this Chapter, attention is drawn to a curious process, whereby a porcelain manufacturer was enabled, on being furnished with an engraved copper-plate, to produce impressions on any scale that might be required, whether larger or smaller than the original. For this purpose no second plate of copper was needed; and the enlarged or diminished copies might be furnished in the course of a very few hours. It is to be regretted that no description was given of the means employed for effecting this curious process; but the Committee, who personally witnessed its execution, expressed themselves perfectly satisfied as to its efficiency, and awarded an honorary gold medal to the inventor.*

CHAP. VII.

ON THE MANUFACTURE OF TOBACCO PIPES.

This Manufacture prosecuted to a great extent.—Description of Material.—Rolling.—Boring.—Moulding.—Polishing.—Baking.—Description of Kiln—Of Crucibles.—Manufacture in Holland.—Originally conveyed there from England.

The manufacture of tobacco pipes forms a branch of the potter's art, which has acquired considerable importance from the extent to which it is prosecuted; and it is at the same time interesting from the nature of the processes employed. A short account of these will, therefore, not be thought misplaced in this treatise.

The clay chiefly employed for the purpose is found in the island of Purbeck, in Dorsetshire, and is preferred on account of its extreme whiteness. Previously to being used, it must be diligently purified from all extraneous matters. The means employed for this latter purpose, being the same as have already been described, their recital may be omitted here.

When the purification is accomplished, and the clay has been formed into cubical masses, weighing each from eighty to one hundred pounds, the workman from time to time cuts off small portions, each sufficient to form one pipe, and, first kneading them thoroughly upon a table, rolls them out to nearly the form and size of pipes, leaving a bulb at the end for the formation of the bowl. In this operation, the skill of the man is made apparent by the near approach which this roll makes to the dimensions actually required. Persons who have had a

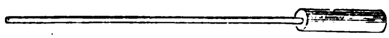
* Ann. de Chim. et de Phys. tom. xiii. p. 94.

competent experience will succeed in this respect to such a point as completely to fill the mould, to which the rolls must afterwards be transferred, leaving but little surplus clay to clip away.

Fig. 5.

When the rolls have been formed for a short time, and by that means have become sufficiently hardened, the workman proceeds to bore the stem by introducing an iron needle. This part of the manufacture calls for a great deal of address, and

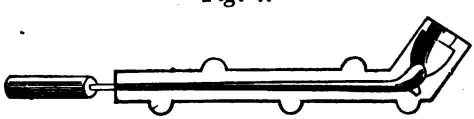
Fig. 6.



can only be satisfactorily accomplished after long practice. In performing it, the roll is taken between two fingers, which follow the point of the needle in its course through the whole length of the stem. Near to its point the needle has a circular enlargement, the progress of which may be felt through the substance of the clay; and thus the execution of the task is somewhat facilitated. The bore must be made as exactly as possible in the axis of the stem; and, in forming it, the needle must be pushed forward by means of its wooden handle, with a gentle and equable pressure. The part which is to form the head or bowl of the pipe is then bent so as to give it the proper inclination.

The mould, into which the stem is next placed, is of copper, and divided into two similar parts. On being put to use, the

Fig. 7.



whole interior surface of both sections must be slightly touched with a brush containing some very limpid oil, that the stem may be afterwards delivered from it without difficulty. The roll of clay being placed in one section, the other is fitted to it according to marks previously made, so as to insure the perfect correspondence of the two parts. The mould is then subjected to the action of a small iron press, in which the two parts

are forced together by means of nuts and screws; and by this means its exterior form, with all its ornaments, is at once given to the pipe.

The head or bowl has yet to be fashioned. This is in part effected by the fore-finger, and more perfectly thereafter by means of a stamp or form attached to the mould, and which by the action of a lever is introduced within the hollow which the finger has made for the purpose. The bore of the stem is then continued into the bowl, by pushing the needle up to its handle; any excessive quantity of clay that may have been used is next cut away, and the pipe is smoothed by means of an iron or copper blade.

The pipes as they are formed are spread out and arranged upon a board, that they may be still further dried; and when they have acquired a certain consistence, any roughnesses that may appear upon the bowl are rubbed away with an appropriate horn instrument, which is provided with a groove, of which the workman avails himself to perfect the circular form and to smooth the edge of the bowl.

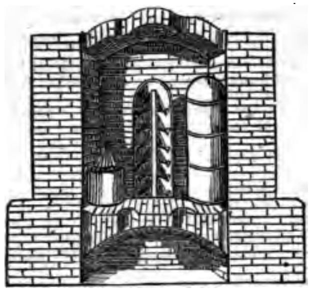
After this the pipes are placed a second time in the moulds, that any imperfections which they have acquired in their shape may be remedied; and they are then left until sufficiently hardened to receive the last polish, which is given by rubbing them with flints bored with holes, some of which are of the same diameter as the stem, while others will admit the head of the pipe. If it should then appear necessary, the workman retouches the different ornaments on the pipe with a kind of bodkin, and the needle is withdrawn from the stem.

These various operations, which bear an appearance of complexity in the narration, are yet so easy of accomplishment, that a clever moulder will furnish 3500 pipes in a week.

The kiln used for baking the pipes is cylindrical; having a circular fireplace at its bottom. With the exception of the spaces required for the circulation of heated air, the interior of the kiln is occupied by crucibles, wherein the pipes are placed. These crucibles, which are made very thin, are composed of the same clay as the pipes, and are strengthened by the insertion of broken pipe-stems. The bottoms are framed of these stems, radiating towards the centre, and having the interstices plastered with pipe clay. The top of each is dome-shaped; and a pillar of clay is placed in the centre through the whole altitude, which serves at once to strengthen the crucible, and to support the stems of the pipes. The side of the crucible is provided with six horizontal ledges, proceeding at equal distances all round, and upon these the bowls of the pipes are arranged, while the stems are made to lean against the central

pillar. The crucible is capable of containing in these six divisions fifty gross of pipes; and, if the heat of the furnace is properly managed, these will be sufficiently baked in seven or eight hours.

Fig. 8



The property possessed by tobacco pipes of adhesiveness to the tongue, is owing to the great affinity which the clay has for water: this quality is much increased by the baking process.

The manufacture of tobacco pipes is prosecuted to a very considerable extent in Holland, whence large quantities have long been exported annually. For the introduction of this art the Dutch are indebted to this country; in proof of which assertion, Mr. Hollis, who passed through the Netherlands in 1748, mentions that, having visited very extensive pipe-works at Gouda, he was informed by the master of it, that even to that day their principal working tools bore English names.

CHAP. VIII.

ON THE PORCELAIN MANUFACTURE OF CHINA.

Obscurity wherein its Origin is shrouded—Chiefly practised at King-te-Ching.—Supposed Superiority of Old China Ware.—Materials employed. —Kao-lin—Pe-tun-tse—Their Preparation.—Oils or Varnishes—Their Composition.—Hao-che—Its Superiority to Kao-lin.—Analysis of Kao-lin.—Extent of Factories at King-te-Ching.—Great Number of Workmen employed.—Preparation of Materials.—Method of fashioning Utensils.—Moulds.—Division of Labor.—Deficiency of Chinese in the Art of Design. —Their Excellent Colors.—Numerous Hands employed in Decorating each Piece.—Bad Effect of this System.—Blue long the only Color used for Painting China Ware.—Mode of Preparing various Colors.—Chinese ignorant of Chemical Science.—Umiam.—Tsou-tchi.—Kia-tsing—Method of forming it.—Chinese Furnaces.—Passion for Old Porcelain.—Ku-tong. —Mock Antiquities.—Reasons for Costliness of China Ware in Europe. —High Prices formerly paid in China.—Finest Specimens not brought to Europe.—Porcelain Tower at Nan-king.—Chinese Potters prepare Materials for the Use of their Descendants.—Common Wares made in China. —Attempt of the Emperor to transfer the Manufacture to Pekin.—His Want of Success.

No success has attended any efforts that have been made to discover the origin of the art of making porcelain in China, and the date of its invention remains veiled in obscurity. The most that is known on this head is gathered from the written annals of Feou-leang, a city belonging to the same district of the empire as King-te-ching, wherein it is recorded that, from the time answering to the year 442 of the Christian era, the last-mentioned place has enjoyed the honor of supplying the imperial court with porcelain, and that one or two mandarins have usually been deputed from Pekin to inspect this part of the workman's labors. The invention of the art would assuredly date from a much earlier period than that here mentioned; as it would be long ere the manufacture arrived at such a state of perfection as to render it an object of interest to the court.

It is a very common opinion in China, that the porcelain ware made by their ancestors was superior in quality to any more recently manufactured. This belief is grounded on the fact, that pieces of porcelain are frequently dug from the earth, which are uniformly found to be of the very finest description. It has been remarked, that this fact is not by any means conclusive evidence upon the subject; the buried pieces were most probably concealed, during periods of civil commotion, on account of their value, and in order to preserve them for their owners, who were without an equal inducement to bury articles of more common use. An opinion likewise prevails, and is supported by reference to the same fact, that the quality of porcelain vessels is improved in beauty by a lengthened burying

in the earth; and the same answer has been applied to this as to the first-mentioned assertion.

The Chinese employ in the composition of their porcelain two kinds of earths, and two oils or varnishes. Of the earths one, which is called kao-lin, is found intermixed with particles of a shining substance resembling mica; the other is known by the name of pe-tun-tse, and is of a brilliant white, exceedingly fine in its grain, and soft to the touch. Both these descriptions of earths are found in mines or quarries situated between twenty and thirty leagues from King-te-ching, to which place they are brought in small vessels, which are continually passing up and down the river of Jao-tcheou for that purpose. The hard blocks of pe-tun-tse are cut from the quarry in the form and about the size of our bricks, and are brought in this state to King-te-ching. The first preparation which these lumps undergo, is that of breaking and pounding them coarsely with iron mallets, and afterwards more completely in mortars with pestles, wrought either by the hand or by a water-wheel. By this means the blocks of pe-tun-tse are reduced to an almost impalpaple powder, which is thrown into an urn-shaped vessel nearly filled with water, and then stirred briskly about, that the particles may be intimately mixed with the water. When this mixing has been effected, and the fluid has been left during a short time to repose, a white creamy substance forms upon the surface, to the depth of two or three inches: this, being skimmed off, is transferred to another vessel, supplied with clear water. The fluid remaining in the first vessel is then again stirred up; another portion forms upon the surface, which in its turn is removed, and added to the first skimming; and this process is continued as long as any creamy substance can be collected from the surface. What remains in the urn-shaped vessel has not been sufficiently ground; and, being collected from the bottom, must be again submitted to the process of grinding.

The skimmings are left to settle in the second vessel, until the solid portion has subsided to the bottom, leaving the supernatant water perfectly clear: this is then poured off; the sediment is transferred to moulds, wherein it remains until nearly dry; and the cakes are then taken out and cut into square pieces of the size most convenient for use. The pe-tun-tse is then in a fit state for combination with kao-lin; and the squares are sold by the hundred to the porcelain makers. It is not often that the manufacturer can venture upon using this material in the state wherein he buys it; the men who have been previously employed in preparing the cakes, most generally mix in the squares as large a portion of foreign matter as they expect

will escape detection: a separation of these previously to the employment of the earth becomes, therefore, needful.

A similar process is followed in the preparation of kao-lin; but this substance being much less hard than pe-tun-tse, less labor is required for its performance.

The two substances described as oil or varnish are procured, one from a combination of pe-tun-tse with another mineral substance, and the other from lime. In the preparation of the first of these, such stones are preferably selected as have the whitest appearance. These undergo the same processes of grinding and washing as have already been described; except that the creamy substance, when it has subsided in the second vessel, is not all put into moulds, but only the upper and finer stratum is gathered for the preparation of this varnish. To each one hundred pounds of the substance thus separated one pound of a mineral called she-kao, which is a kind of gypsum, is added. This stone, which resembles alum in its appearance, is first raised in a furnace to a red heat; and then reduced, by pounding and rubbing in a mortar, to a very fine powder; in which state its union with the purified pe-tun-tse is effected, the consistence of the compound being perfectly fluid.

The preparation of what is called *oil of lime*, the fourth ingredient required, is thus managed:—Lumps of quicklime are first sprinkled with water, and reduced to a powder; upon this a bed of dried fern is placed; then another layer of lime, covered again by fern; and so on alternately, until the pile having reached a moderate height, fire is applied: and when the whole of the fern is consumed, the ashes are collected and strewn upon fresh beds of fern, which are again fired; and this burning process is repeated five, six, or more times successively,—it being held that the more frequently the ashes are burnt, the better is the quality of the product. Some ancient Chinese annals affirm that, instead of fern, the wood of a kind of medlar tree was anciently used; and that the quality of the porcelain was in consequence more beautiful. This wood is now become too scarce to be employed for the purpose. The lime and fern ashes are next thrown into a vessel containing fair water, and she-kao is added in the same proportion as to the creamy dilution of pe-tun-tse. This she-kao dissolves; and the solid matter being separated from the water by subsidence, and removed in a tolerably fluid state, forms what the Chinese manufacturers call the oil of lime, to the agency of which they attribute all the lustrous appearance of their porcelain. Lime, when uncombined, is infusible, except at a very intense degree of heat; and the fern ashes thus added, are essential, acting as a flux, and promoting the fusion of the glaze in the furnace. In mix-

ing these two varnishes together, only one measure of the oil of lime is added to ten measures of that of pe-tun-tse, care being taken that the consistence of both is equal. The oil of lime is easily, and to the seller profitably, adulterated by the addition of water, combined with such a farther portion of she-kao as preserves its proper degree of consistency.

It is said that, since the time when D'Entrecolles communicated his observations on the porcelain manufacture in China, the potters there have discovered a new species of mineral, which can be advantageously used in the preparation of porcelain. This is a species of chalky stone, which bears some outward resemblance to soap, and is declared to possess considerable medicinal virtues. It is called hao-che; and when used instead of kao-lin, the result is porcelain of very fine grain, exceedingly light, and much better qualified for receiving colors, but more brittle, and far dearer in its cost, than the commoner kind of ware, the price of hao-che being three times that paid for kao-lin. This new substance, when taken from the mine, undergoes the operation of a careful washing, to separate from it a kind of yellow earth with which it is always found accompanied: it is then pounded, and treated exactly in a similar manner to that described in the preparation of kao-lin. It is affirmed that hao-che, thus purified, is capable of being made into porcelain without any admixture.

It is the kao-lin which, although much softer than the pe-tun-tse when taken from the quarry, gives strength and body to the porcelain; and, consequently, this, or some substitute possessing the same quality, forms an indispensable ingredient in its composition. It is related that some Europeans, having privately obtained some blocks of pe-tun-tse in China, and conveyed them to their own country, vainly endeavored to convert them into porcelain; which becoming known to some Chinese manufacturers, they deridingly remarked, "that certainly the Europeans must be a wonderful people, to go about to make a body whose flesh was to sustain itself without bones."

Kao-lin is known, from the particles of mica which it contains, to have its origin in felspar, or graphic granite. It is infusible with the heat of a porcelain furnace even in China, the degree of which must be most tremendous, as some of the materials employed in their glazes could not be vitrified at a lower temperature than would suffice to fuse Cornish granite. The kao-lin quarries of China agree with the mines of Alençon and St. Yrieux near Limoges, where a similar earth is found—all of them having a super-stratum of red, friable, micaceous rock, of the texture of gneiss. The constituent ingredients of kao-lin are found to be—silica 52, alumina 42, oxide of iron 0.33.

The factories employed at King-te-ching for the porcelain manufacture are of great extent. They are walled round, and contain sheds under which the processes are carried on, as well as dwellings for the workmen. The number of people employed in one of these factories is very great, as must appear when it is considered that almost every piece of porcelain produced, however small, passes through more than sixty different hands before it reaches a state of perfectness.

When the purification of the two earths has been completed by the processes already described, the next operation is to unite tnem in the requisite proportions. The relative quantities of these materials depend upon the quality which it is desired to give to the porcelain.—For the finest kind, they mix the kaolin and pe-tun-tse in equal quantities, and diminish the proportion of the former according as coarser kinds of ware are required; but, for the very coarsest descriptions, the kao-lin never forms less than one fourth of the mass.

The most laborious part of the whole operations of the factory, is that of intimately kneading and working the earths together, so as to form of the two one homogeneous mass. This is performed in pits, which are paved and cemented, wherein the workmen continually trample upon the paste, bringing together fresh portions by turning it over; and this work is continued without intermission, one set of workmen relieving another at intervals, as each becomes fatigued by the labor, until the mass is thought to be thoroughly mixed, and has been brought to a consistence proper for being moulded by the potter. The mixture is then removed from the pit; and being divided into small portions, is again kneaded with the hands upon large slates provided for the purpose. Too much careful industry can hardly be exercised in this operation. If the smallest drop of water or globule of air be left remaining in any portion of the mass, the article which contains that portion will infallibly be spoiled by the expansion of the fluid in the oven. The smallest grain of sand, or even a single hair, left in the paste, would be equally prejudicial, occasioning the porcelain to run, or crack, or warp in the baking.

The pieces are fashioned by the Chinese workmen in a manner so similar to that adopted in our own potteries, that it would be useless to narrate the process.

The moulds used in the potteries of China for forming pieces of multiform shape are made in several portions or divisions, which are brought together when used. They are made of a yellow unctuous earth, which occurs abundantly in quarries near to King-te-ching; and its preparation by kneading and beating is very similar to that bestowed on the porcelain earths. When

made and used with care, these moulds will last for a long time. The Chinese workmen are not content with the work as delivered from the moulds, but uniformly finish the article by the hand, using a variety of chisels and other tools to touch up the various lines and forms given by the mould, as well as to supply its probable deficiencies; so that the potter executes, in some sort, the art of a sculptor. In works where different objects appear in relievo, these are made separately, and added in the way commonly used in our own potteries.

It may give some idea of the number of hands employed in the perfecting of every piece of porcelain to state what D'Entrecolles has related to occur with the commonest description of tea-cup. The potter has the management of the wheel; and under his hands the cup assumes its form, height, and diameter. It may be well imagined that this workman does not bestow much labor upon his task, when we are told that for fashioning twenty-six cups he receives a sum equivalent to about three farthings of our money: the cup, accordingly, is delivered by him in a very imperfect state to a second workman, who fits it to its base. From him it passes immediately to a third man, who, by means of a mould, placed on a kind of lathe, corrects the imperfections of its shape. A fourth man, by the aid of a chisel, corrects the inequalities and unevennesses of the edges, and pares the cup to a substance which renders it sufficiently transparent. In the course of this operation he has frequently recourse to water, in order by moistening to prevent the cracking or breaking of the cup. A fifth workman then smooths the inside by turning it gently on a mould. Considerable care is required in this stage to prevent any warping or the formation of any cavity in the cup. Other men then, according to the description of cup which it is intended to produce, add either the handle, or some ornaments in relievo, or make sunken impressions. The operation that immediately precedes the first baking of the cup, is that of rounding and hollowing the inside of its foot: this is performed with a chisel.

By this division of labor, the work is found to proceed with greater regularity and rapidity. Incessant attention to one operation, and that of a very simple kind, gives to each workman considerable dexterity and facility in its performance; and no time is lost in the changing of implements, as must be the case if one man had to conduct the manufacture through its several stages.

Very large pieces of porcelain are made at King-te-ching. These are sometimes of such magnitude, that they must first be formed in two, three, or more sections; each one of which requires to be supported during its formation by three, or more

men. When the different portions are sufficiently dry, they are united together with slip, in the same manner as handles are attached; and the seams are smoothed and polished with an iron instrument, so that, upon their being afterwards covered with varnish, it is not possible to discern the points of junction.

The celebrated traveller Marco Polo mentions the vast extent to which the manufacture was carried at the time of his residence in the Celestial Empire, and states that eight porcelain cups might then be purchased at the low price of a Venetian groat.*

Among the Chinese, the art of design has never advanced beyond the very first steps. These people appear ignorant of the commonest rules of perspective; and their drawing, especially where attempts are made to describe the human figure, is wretched in the extreme. To make some amends for this, the colors which they employ are exceedingly lively and brilliant, so that European artists have found it a difficult task to vie with them in this respect. In examining the painted porcelain of this singular people, one is almost led to imagine that their artists have been debarred the sight of the objects which they attempt to represent, as otherwise some among them must surely have possessed sufficient innate taste to have led him from the general track, and instead of the miserable caricatures that disgrace their labors, to have made some approach towards the truth in his delineation of natural objects.

The system of distributing the work among a great number of hands, which is found so successful in the formation of porcelain, is also pursued in the painting department. One artist forms only colored circles about the edges; another traces flowers, which a third paints; a fourth delineates nothing but mountains; a fifth describes water; a sixth traces the outline of birds, which a seventh fills up with colors. Other artists trace and color animals; others again perform the same tasks with the human figure, and in this way every object of art and nature found upon their porcelain is the work of a particular artist, who does not attempt the delineation of any other subject. To this system, so useful in conducting every merely mechanical operation, may possibly be owing the continued adherence to old and faulty methods. The celerity which it is calculated to produce is unfriendly to the improvements suggested by genius; and if even one artist among the crowd should be found with taste enough to aim at forming and embodying juster conceptions, his approaches to nature would only

* Marsden's translation, 4to edition, page 560.

serve to render more glaring the deformities produced by his fellow-laborers, and would, therefore, be wholly inadmissible.

It is said, that for many ages the Chinese used only white porcelain. Tradition adds, that its whiteness was most brilliant, that the pieces were altogether faultless, and that the only name by which they were known when exported to other kingdoms was that of "the precious jewels of jao tcheou." Blue was the first color wherewith they ornamented pottery, but the employment of all other colors very speedily followed upon the introduction of this one. At first, and for a long time, their blue color was prepared from a very fine kind of lapis lazuli, which is native with them; but they now import smalt from England, at a price so much below that which their own pigment had cost, that they have abandoned its manufacture, and depend upon their foreign supply. The fine deep-blue sometimes found upon specimens of old Chinese porcelain is much admired and valued by *virtuosi*, and it is regretted that this color is not used at present. It has been conjectured that the Chinese, who unquestionably possess cobalt, most probably employed its oxide also in the production of this esteemed blue color before they were enabled by their commerce with Europeans to substitute for it our cheaper pigment; that their method of preparing the ore of cobalt was such, that it retained the arsenic with which it is always found in combination, and that, consequently, its color proved much deeper and richer than the preparation made by us from the same mineral. Our process being performed in a reverberatory furnace, the arsenic is driven off in fumes. There are some kinds of cobalt which are made to yield smalt without this previous roasting, and the superior color which in such case is always produced is attributed to the presence of arsenic; since if this mineral be added to smalt while in a state of fusion, the color will be rendered much deeper. The preparation of smalt from cobalt without the aid of fire is more expensive and the produce less in quantity than where the common process is followed. The French manufacturers procure their smalt by dissolving cobalt in nitric acid (the aqua fortis of commerce), and then precipitating; and it might be well for our porcelain makers to try the effect of this method.

The red color used by the Chinese is made from common green vitriol or copperas (proto-sulphate of iron), which goes with them by the name of tsa-fan. This material they calcine in a crucible, continuing to apply fire for so long a time as thick black fumes are seen to escape from a hole made in the top of the crucible; but when these fumes are succeeded by a

light and thin cloud, they judge that the process has been carried sufficiently far, and remove the crucible from the furnace, previously, however, withdrawing a small quantity of the color for inspection, as the test here mentioned is not unerring. When the color proves good, the crucible is left to cool gradually, a cake of red matter is then found at the bottom, and a further quantity, in the form of fine powder adhering to its sides. This latter, being the purest and finest color, is kept separate from the cake. Copperas affords about one fourth of its weight of this color, which alone is used for producing all the various shades of red in the porcelain works of King-te-ching.

White porcelain, made in China, owes much of the fine brilliancy of its color to the oils or varnishes before described; but when a brighter and finer hue than can be thus produced is needed, a mixture of the following kind is prepared. The shores of some of their rivers furnish a species of agate, which is without veins and nearly transparent, so that it approaches to the nature of crystal. This stone is calcined to a white powder, and then ground as fine as possible. To every ounce of this they add two ounces of white lead (ceruse,) also in fine powder, and these being mixed with the varnish, the whole is laid on the porcelain in the same way as other colors. According to the descriptions given to us, this compound, besides being used for the production of a brilliant white, forms also the ground or basis of several other beautiful colors. Their green, which is prepared from the oxide of copper, is said to be converted into a fine violet color by admixture with the white just described. Such a change as this must of course be the effect of chemical action promoted by the heat of the furnace. The mere mechanical mixture of white with green would only reduce the depth of its shade. A very small proportion of the white suffices, it is said, to produce a very deep violet, and the hue is rendered lighter in proportion as the quantity of white is increased. Their yellow is said to result from the mixture, in due proportions, of this white with copperas (proto-sulphate of iron). The accounts we have of those processes among the Chinese, which depend upon chemical laws, are given with so little regard to accuracy, and betray so great a want of scientific acquirement, that these descriptions of their mode of preparing colors cannot be received with any satisfaction.

The Chinese painters of porcelain usually mix their colors with gum water, in which a small portion of either saltpetre (nitrate of potass), white lead, or copperas has been first dissolved. Where a red color is used, the porcelain oil or varnish is applied with it. This color is laid on the ware when in the state of biscuit, that is, when it has been once in the oven; but

it requires the heat of the second baking to bring out all its requisite shades and tints.

Black porcelain, ornamented with gold, known under the name of *umiam*, is much esteemed in the East. The black is produced by mixing three drachms of deep blue, with seven drachms of the varnish, which they call oil of stones. The black thus prepared is laid on when the porcelain is first dried, and when the black is also thoroughly dry, the vessel is baked. The gold is then laid on, and the piece is subjected to another baking in a furnace peculiarly constructed for the purpose. The gold is ground in water to a very fine powder; and when this has been very gradually dried in the shade, one tenth of its weight of white lead is added, the mixture is incorporated with gum water, and laid on in the same manner as colors are applied.

The Chinese have a kind of porcelain, which is in much repute with them, called *tsou-tchi*. This has the appearance of having been broken, and of having its fractured edges brought together and cemented, and then covered with the varnish originally used. This effect is produced through the peculiar nature of the varnish employed, which never spreads evenly, but has a tendency when in fusion to run into veins and ridges of various and uncertain forms. This varnish is made from a sort of agate stones, reduced by calcination to a white powder, which after being long ground in a mortar is carefully washed, and used when of the consistence of cream. It has been suggested that crystal would probably answer this purpose as well as the coarse agates of the Chinese; and among all the demands of fashion which is ever seeking for something new, it might perhaps serve the interest of some manufacturer to put this suggestion to the proof.

Another kind of porcelain, much esteemed by the Chinese, is called by them *kia-tsing*, which signifies pressed azure. In vessels of this description the colors appear only when the cups are filled with liquid. The manner of making porcelain so as to produce this effect is as follows:—The cup is made very thin, and after having been once baked, the colors are applied in the required forms on its inner surface. When dry, a coating of porcelain earth, the same as that already composing the cup, must be laid on the inside; over this, the usual varnish is laid, so that the colored figures are inclosed between two coats or bodies of the ware. The outside, already very thin, is then ground down almost to the painted figures, which are thus made to appear externally, when they must be covered anew with a coat of varnish so as to be scarcely perceptible from the outside, until the vessel being filled with liquid, this

acts as a kind of foil behind, and throws out the figures which before were obscured. So much carefulness is called for in the production of kia-tsing, that the art is very seldom practised.

Another admired art among this people is that of producing the semblance of various figures upon pure white porcelain, whose surfaces are yet entirely smooth. Having fashioned a vessel, with the finest materials and extremely thin, it must be polished inside and out, when a stamp cut with the requisite figures in relief must be pressed upon the inner surface of the unbaked vessel. The finest white varnish must next be applied over its entire surfaces, so that the cavities impressed by the stamp are filled by it, and the smoothness of the inner surface is restored. When the ware is baked, the varying thicknesses of the more opaque varnish will be apparent through the transparent sides of the cup, and the whole of the figures will then be seen as finely and accurately traced as if painted on the outside.

The methods employed by the manufacturers of King-te-ching in applying the varnish, vary with the different qualities of the wares under operation. For very fine and thin porcelain two exceedingly thin coatings are very carefully applied, and some dexterity is required, both with regard to the quantity laid on, and the equable manner of its application. To pieces of inferior quality, as much varnish is applied in one coating as is comprised in the two layers just mentioned. The foot of the vessel is never properly formed until this stage of the manufacture, and after the painting and varnishing have been completed, when this part is finished on the wheel, and varnished likewise. The work is then fit to be placed in the oven.

The construction of furnaces and the system followed in baking porcelain in China differ so little from the structure and method pursued in England, that little need be said here concerning them. It has already been mentioned that the nature of the materials employed calls for a much higher degree of heat than is necessary in our potteries. To insure this, the Chinese are very careful in providing a rapid draught, and in the incessant feeding of their furnaces with small billets of wood, so as to insure its most rapid combustion. The learned Jesuit D'Entrecolles observes, as a thing quite unaccountable, and even inconceivable, if he had not witnessed the fact, that notwithstanding the enormous consumption of wood during so many hours, none of its ashes are ever found upon the hearth of the oven. There would have been greater reason for astonishment had the contrary fact appeared. The rapid draught excited by the disposition of the oven, and the excessive degree

of its temperature, would serve to carry away completely through the flue so light a substance as wood ashes.

The taste for old porcelain appears to prevail fully as much in China as it has ever done in this country. It is asserted by some persons, that such as was made in former days was not only composed of finer materials, but was more perfect in the mode of its manufacture. Unfortunately for this assertion, there are workmen at King-te-ching, who make it their occupation to counterfeit these much-coveted relics of antiquity, which are called *ku-tong*, and in this they succeed so as to deceive the most observant connoisseurs. In the preparation of these mock antiques there is but little variation from the methods usually practised. They are made thicker than modern porcelain, and are made to undergo the ceremony of burial for one or two months in the most lothesome sink of filth which can be found, by which means every appearance of newness is effaced.

Several reasons are assigned for the high price at which Chinese porcelain is sold in Europe. One of these is, that owing to their very unscientific manner of conducting the baking process, it rarely happens that some, and sometimes a very considerable portion, is not spoilt by unequal or excessive heat, and converted to a deformed and shapeless mass. Another reason for dearness is, the constantly diminishing supply of the materials used, and more especially of fuel, which becomes very expensive. It is added, that as those pieces which are prepared for the markets of Europe, are of patterns unacceptable to the taste of home consumers, and as the factors are exceedingly particular in rejecting every article which exhibits the slightest defect either in form or color, the prices paid to the manufacturers for such as are accepted must be sufficiently high to include the cost of those which are rejected. Notwithstanding these circumstances, the prices at which porcelain is now furnished in China are materially less than those demanded in ancient times, when, we are informed, as much as 100 crowns were given for a single urn at the seat of manufacture. The emperor monopolizes the finest specimens of porcelain manufactured in his dominions, and it has thence been asserted, that none which has ever found its way to Europe gives an adequate idea of the perfection to which the Chinese have attained in this manufacture. The Porcelain Tower erected at Nan-king offers proof sufficient of the very durable nature of their manufacture. This building is of an octagonal shape, is of nine stories, and very nearly 300 feet high, and its entire surface is covered with porcelain of the finest quality. Although this singular and beautiful edifice has been erected more than 400

years, it has hitherto withstood all the alternations of seasons, and every variety of weather, without exhibiting the smallest symptom of deterioration.

The intimate mixture of the two earthy materials so essential to the production of good porcelain is much more perfectly attained, if, after the employment of the mechanical means already described, the united mass be left for a considerable time before its employment. The Chinese frequently extend this interval to a space of fifteen or twenty years; and instances are not uncommon, where the provident care of a parent leads him to prepare as much porcelain clay as will suffice for his son's use, during the whole period of his life.

The Chinese excel in the manufacture of brown earthenware, which being sold at a very low price, is used commonly throughout the empire. Porous vessels for cooling water are also made by them of fuller's earth, which is principally composed of alumine and very pure silex, in combination with oxide of iron. The name by which porcelain is distinguished in this, the country of its earliest production, is *tse-ki*.

An attempt was once made by the government to remove the seat of manufacture to the imperial city of Pekin. This, however, although no effort was spared in the business, proved unsuccessful, and the sole prosecution of the art reverted to King-te-ching, where, according to the statement of different travellers, there are established 500 factories, giving employment to more than a million of artisans. There appears no good reason for believing that the manufacture would not have been prosecuted with equal success at Pekin, if those who directed it had been so disposed; and the different result which has been recorded is supposed to have arisen from the disinclination of the manufacturers to be brought so closely within the control of a government supereminently famed for meddling with the private concerns of its subjects.

MANUFACTURE

OF

GLASS.

A TREATISE

ON THE

PROGRESSIVE IMPROVEMENT AND PRESENT STATE

OF THE

MANUFACTURE OF GLASS.

CHAPTER I.

ON THE NATURE AND PROPERTIES OF GLASS, AND THE HISTORY OF ITS MANUFACTURE.

Nature of Glass.—Its various Properties.—Its Utility.—The Assistance it lends to Science.—Excessive Prices formerly paid.—Origin of its English Name.—Aristotle's Problems.—First Invention ascribed to the Phœnicians.—Manufactories of Alexandria.—Utensils found in Herculaneum.—Malleable Glass.—Tax on Glass by Alexander Severus.—Portland Vase.—Glass employed in forming Windows.—Privileges granted to Manufacturers in France.—Plate-Glass Casting.—Establishment at St. Gobain.—Its early Failure, and Revival.—Manufacture commenced in England.—Of Flint Glass.—Of Plate Glass.—Chinese unacquainted with Glass-making.—Importance of the Manufacture in England.—Glass made a Source of Revenue.

Many circumstances contribute to render glass one of the most curious and interesting of manufactured substances.

Although perfectly transparent itself, not one of the materials of which it is made partakes of that quality. Exceedingly brittle while cold, it becomes, by the application of heat, so remarkably flexible and tenacious as to be convertible into every form that fancy may dictate or convenience suggest. Its great ductility is shown in a very striking manner by the slender filaments—small as the fibres of spider's web—into which it is spun for ornamental purposes. Many hundred feet of these filaments may be drawn out from a heated mass in the space of one minute. Its pliancy and elasticity are proved by the facility with which, when in the state just mentioned, it may be bent and retained in various forms, and by the energy wherewith its original shape is resumed at the moment of release from its constrained position.

The impermeability of glass to water, even under a considerable degree of pressure, is well ascertained. A few years ago, the reverend Mr. Campbell, while on a voyage to Southern Africa, among other philosophical experiments wherewith he amused himself, caused two globular glass bottles hermetically sealed to be lowered by means of leaden weights to the depth of 1200 feet beneath the surface of the sea. These,

through the united and continuous exertions of ten men during fifteen minutes, were again drawn up, and were found to be perfectly empty.

The continued exposure of glass to the greatest heat whereby it is melted, does not produce any sensible diminution in its weight and quantity, or any alteration of its properties. It is capable of receiving colors, and of retaining them in all their lustre for an indefinite period. The strongest acids—with one exception that will be noticed—have no effect upon it; a circumstance that renders glass additionally useful in assisting the researches of chemists. It is capable of receiving the most perfect polish, preserves all its beauty, and does not lose the smallest portion of its substance by the longest and most frequent use.

The admirable qualities and important uses of glass have been so happily pointed out by one of the most celebrated writers of the last century, that no apology will be needed for the insertion of the passage.

"Who, when he saw the first sand or ashes by a casual intenseness of heat melted into a metalline form, rugged with excrescences, and clouded with impurities, would have imagined that in this shapeless lump lay concealed so many conveniences of life as would in time constitute a great part of the happiness of the world? Yet by some such fortuitous liquefaction was mankind taught to procure a body at once in a high degree solid and transparent, which might admit the light of the sun, and exclude the violence of the wind; which might extend the sight of the philosopher to new ranges of existence, and charm him at one time with the unbounded extent of the material creation, and at another with the endless subordination of animal life; and what is yet of more importance, might supply the decays of nature, and succor old age with subsidiary sight. Thus was the first artificer in glass employed, though without his own knowledge or expectation. He was facilitating and prolonging the enjoyment of light, enlarging the avenues of science, and conferring the highest and most lasting pleasures; he was enabling the student to contemplate nature, and the beauty to behold herself." *

The utility of a substance which is daily and hourly rendered serviceable by all classes of persons in almost every human habitation cannot need to be exemplified. The aids which it offers to scientific researches are almost equally apparent. To notice the particular arrangements whereby the chemist, the naturalist, or the astronomer avails himself of some of the va-

* Rambler, No. ix.

rious properties of glass in pursuing his investigations, would lead to descriptions which, although interesting in a high degree, are foreign to the object of this treatise, wherein little more than incidental notices can be given, on points that have relation to improvements in the manufacture.

It may be useful, however, to notice here an error, not unfrequently made, from observing glass to be the only transparent material used in making spectacles, opera glasses, and other optical instruments. Persons are induced, from this circumstance, to ascribe to the peculiar quality of glass the exclusive power of modifying the apparent magnitude, brightness, and distinctness, of objects seen through it. This, however, is not an exclusive property of glass, but belongs to every transparent substance having a density different from that of the air which surrounds the observer. It depends also, not alone on the inherent qualities and density of the transparent substance through which the objects are viewed, but also on the form of the surfaces which bound that substance, and on various other circumstances not necessary to be noticed more particularly here. The reader will, therefore, recollect, that the optical properties of glass are common to the diamond and other transparent solids, to all transparent liquids, and even to gases. Glass is commonly used on account of its cheapness and durability, and for other reasons of convenience.

It is impossible, however, wholly to dismiss this subject unaccompanied by expressions of admiration at the genius of those master spirits, who, by their discoveries and inventions, have rendered glass subservient to purposes that open and enlarge the field of human knowledge in some of those branches of natural philosophy which tend most to refine the nature and exalt the character of man.

Familiarized as we are to the use and appearance of glass, yet no person can ever become indifferent to its advantages, or insensible to its beauty. Neither can we feel astonishment at the admiration which induced the ancients, while the art of making it was little practised, and in those countries where it was not yet established, so greatly to covet the possession of glass vessels as to purchase them at prices which to us appear exorbitant. We are told that the emperor Nero gave for two cups with handles 6000 sestertia, a sum nearly equal to 50,000*l.* of our money. These vessels were not of any extraordinary size, but were thus highly valued on account of their perfect transparence, and resemblance to crystal.

The name whereby this material is known to us is generally said to be derived from the Latin, and to have been suggested by its great similarity in appearance to ice (*glacies.*) It has

been remarked, however, that the common Latin designation is *vitrum*; and as the Romans gave this name also to the plant which we call *woad*, and which our remote ancestors called *glastum*, it is imagined that glass obtained the same distinctive appellation, because of the bluish tint which it usually exhibited. There is as little probable foundation for one as for the other conjecture, nor is the question of much importance, since, whichever way it might be determined, no light would be thereby thrown upon any point of interest concerning the origin of the manufacture, which, although involved in the most impenetrable mystery, is yet known to have existed long before its introduction among the Romans.

The passage in the book of Job (ch. xxxvii. v. 18.) wherein mention is supposed to be made of glass, has been adduced by Neri in proof of its remote origin. Unfortunately for the correctness of this opinion it has been found, that in many ancient versions, instead of the *glass* of the Vulgate and Septuagint, other substances which have diaphanous and shining properties are mentioned. In fact, the word in the original Hebrew has been frequently used, according to the fancy of translators, to signify different bodies possessing lustre and transparency.

The two problems of Aristotle—if, indeed, they were propounded by that philosopher—"Why do we see through glass?" and "Why is it not malleable?" comprise, perhaps, the earliest written mention made of the substance. Theophrastus, whose writings are not half a century later than the time of Aristotle, mentions the use of sand from the river Belus in making glass; and from that date (300 years B. C.) a knowledge of the material was pretty generally diffused. If reliance is to be placed upon the statement, that the celebrated sphere of Archimedes was made of glass, the art must in his time (200 years B. C.) have arrived at a considerable degree of perfection.

Many authorities concur in assigning the merit of the invention to the Phœnicians; and the assertion of Pliny is often repeated, which attributes the discovery to accident. Some storm-driven mariners were boiling their food on the sands at the mouth of the river Belus—a small stream running from the foot of Mount Carmel in Galilee—where the herb kali was growing abundantly, and are said to have perceived that the sand, when incorporated with the ashes of this plant, melted and ran into a vitreous substance. It is certain that the sand about this spot was well adapted to the manufacture of glass, and probably the glass-houses of Tyre and Sidon were supplied thence with this material, which may have given rise to the tradition.

That the ancient Egyptians were well acquainted with the method of making glass cannot be doubted. The beads wherewith some mummies are adorned, although composed of earthenware, have an external covering of glaze, which is true glass covered with a metallic oxide; and recent searchers have discovered among the tombs at Thebes some pieces of glass of a blue color, similar in their composition to the glazing on the beads just mentioned.

The glass-houses of Alexandria were long famed for the skill and ingenuity displayed by their workmen. The Romans were, at one time, supplied with a great part of their glass ware from that city. A coarse and impure manufacture of drinking vessels had been prosecuted at Rome from the time of Nero; but the art could have made only a slow progress notwithstanding the encouragement offered by the high prices at which glass wares of foreign make were sold in the imperial city. The emperor Hadrian, while at Alexandria, received from a priest some glass cups of various colors, which had been used in the worship of the temple, and transmitted them to Rome as objects of great value and curiosity, with an injunction that they should be used on festivals and other great occasions.

Utensils of glass have been found among the ruins of Herculaneum, which city was destroyed in the reign of the emperor Titus, by the same eruption of Mount Vesuvius which cost the elder Pliny his life. It does not appear that glass was used for admitting light to dwellings in Herculaneum, the largest houses having windows made with a species of transparent talc.

In the British Museum are four large cinerary urns made of green glass, which have been pronounced by a very competent authority favorable specimens of the proficiency of the ancients in the art of glass-blowing. These are round vases of an elegant form, furnished with covers and two double handles. The formation of these handles is, it is said, "such as must convince any person capable of appreciating the difficulties which even the modern glass-maker would have to surmount in their execution, that the ancients were well acquainted with certain branches of the manufacture." *

Several ancient authors (*Dion Cassius*, *Petronius Arbiter*, and *Isodorus*) relate, that in the reign of Tiberius, an architect, who had been banished from Rome on account of his great popularity, having, in his retirement, discovered the means of so far altering the nature of glass as to render it malleable, ventured to return to Rome, in the hope of securing both a re-

* Memoir on Glass Incrustations, by A. Pellatt, Esq.

mission of his sentence and a reward for his invention. This discovery not agreeing, however, with the supposed interests of the tyrant, who feared lest the value of gold might be lowered by its means, the architect was beheaded, and his secret died with him. This is, probably, only another version of the story related by Pliny, of the same important discovery having been made by an artist in Rome, when such of the populace as imagined that their interests would be injuriously affected thereby conspired together and destroyed his dwelling.

A similar discovery, attended by results as unsatisfactory, and which is said to have occurred in France in the more modern times of Louis XIII., is recorded by Blancourt. He says, that the inventor having presented a bust formed of malleable glass to the cardinal Richelieu, was rewarded for his ingenuity by perpetual imprisonment, lest the "vested interests" of French glass manufacturers might be injured by the discovery.

Without venturing altogether to deny the truth of these stories, it would be hard to subject to the charge of presumption those persons who entertain doubts upon the matter. It does not, certainly, prove the incorrectness of the statements, that no subsequent examiner into the arcana of nature has been equally fortunate; and it is assuredly *possible* that some successful investigator may yet be the means of revealing that which has already been thus ascribed to more than one experimenter.

Improbable as the achievement of this would seem, it would be scarcely more extraordinary than the transformation of linen rags into sugar, or the conversion of saw-dust into "wholesome, palatable, and nutritious food." The purposes both of use and of ornament to which glass would in such a case be applied are almost endless, and their importance can hardly be overrated; nor should we in these days have occasion to fear, lest the insensate obstructions of some modern Tiberius or Richelieu should step between the discoverer and the promulgation of his secret.

According to our present amount of knowledge, the chance of realizing such a discovery is, however, limited within the barest possibility. The quality of malleability is in direct contradiction to that of vitrification; the existence of the one state seems to be incompatible with that of the other. Some metallic substances when greatly urged by fire are made to approach towards the state of glass, and then lose their malleability; a fact which almost implies the impossibility of imparting the latter property to glass. Kunkel has indeed observed, that it is possible to produce a composition having an external glassy appearance, which should be pliant and capable of being

wrought under the hammer; and Neumann tells us, that in the fusion of muriate of silver a ductile kind of glass is formed, which may be moulded or turned into different figures, and which may be pronounced in some measure malleable; facts to which Henckel has referred in order to account for the traditionary stories of the ancients.

The Latin writers of the Augustan age make frequent mention of glass. Virgil compares to it the clearness of the water in the Fucine Lake (Æn. vii. 759.); and Horace speaks of the lustre and transparency of glass in a way which shows that it could then be made with a considerable degree of perfection. In the year 220 a tax was laid by Alexander Severus upon the glass manufacturers of Rome, who at this time existed in such numbers, that a principal quarter was assigned to them in that city, wherein they might carry on their processes. This tax was still levied in the reign of Aurelian.

The most celebrated specimen of antique glass is the vase, which during more than two centuries ornamented the Barberina palace, and which, having been subsequently purchased by the late duchess of Portland, is better known in this country as the Portland vase. This much-admired production was found about the middle of the sixteenth century, inclosed in a marble sarcophagus, and deposited in the tomb of Alexander Severus, who died in the year 235. The body of this vase, which for a long time was erroneously supposed to be formed of porcelain, is made of deep blue glass, and is ornamented with white opaque figures in bas-relief, which are designed and sculptured in the style of cameos with a degree of skill which is truly admirable.

Glass melted and cast into plates, is said by St. Jerome to have been used in his time (A. D. 422,) to form windows. About a century later, Paulus Silentiarius mentions the windows of the church of St. Sophia at Constantinople which were covered with glass; and from this period frequent allusions to the similar use of glass are met with in various authors.

Long before the establishment of the manufacture within this island, glass was known and used in England. The Venetians who traded with this country in very remote times furnished this among other articles of commerce in exchange for tin. The erudite Pennant is of opinion, that glass-making in Britain dates prior to the Roman invasion. The Druids were accustomed to impose upon their more ignorant followers by means of clumsily-formed beads of colored glass, which they pretended were endued with the quality of guarding their possessors from evil.

The venerable Bede, who lived very near the time, and who

therefore had good opportunities for ascertaining the fact, has asserted in his history of Weremouth, that in the year 674 the abbot Benedict sent for artists from beyond seas to glaze the windows of the church and monastery of Weremouth in Durham, and that these men were our first instructors in the art of making window-glass. This art, however, took root but slowly among us; and it was not until the eleventh century that glass windows were at all commonly used, either in private dwellings or in public and religious edifices. Previously to this time, light was imperfectly transmitted through linen cloths or wooden lattices. The houses of the commoner people were not, indeed, furnished with this luxury until the thirteenth and fourteenth centuries, in which respect our ancestors were greatly behind the inhabitants of Italy and France.

The following curious entry, extracted from the Northumberland household book, makes it apparent that at a much later period than the one just mentioned, the comfort of glazed windows was not considered as a matter of course even in establishments where great state and magnificence were maintained. This entry occurs in the minutes of a survey of Alnwick Castle made in the year 1567:—

"And because throwe extream windes the glasses of the windowes of this and other my lords castels and houses here in the country dooth decay and waste, yt were good the whole leightes of everie windowe at the departure of his lordshippe from lyinge at anie of his sade castels and houses, and dowring the time of his lordshippes absence or others lyinge in them were taken doune and lade up in safetie; and at sooch tyme as ether his lordshippe or anie other sholde lye at anie of the sade places, the same might then be set uppe of newe with smale charges to his lordshippe; whereas now the decaye thereof shall be verie costlie and chargeable to be repayred."

We learn also from Ray's Itinerary (p. 187), that "in Scotland, as late as 1661, the windows of the ordinary country houses were not glazed, and only the upper parts of those of even the king's palaces had glass, the lower ones having only two wooden shutters to open at pleasure and admit the fresh air."

When desirous in former times of giving encouragement to some important manufactures, the government of France was induced to declare their prosecution to be nowise incompatible with the dignity of aristocratic blood. Early in the fourteenth century that government made a concession in favor of glass-making greatly beyond this point, decreeing, not only that no derogation from nobility should follow the practice of the art, but that none save gentlemen, or the sons of noblemen, should venture to engage in any of its branches, even as working ar-

tisans. This restriction was accompanied by the grant of a royal charter of incorporation conveying various important privileges, under which the occupation became eventually a source of great wealth to several families of distinction, whose descendants have at times attained to some of the highest dignities of the state.

The good policy is apparent of thus holding forth inducements to the only parties then qualified by the possession of capital, and probably also by their intelligence, to establish works upon a scale that could lead either to national advantage or individual profit. A middle class of persons, springing from the lower orders, have since gradually placed themselves at least upon a level in point of intelligence with those of more illustrious descent; and by the exercise of that intelligence, conjointly with prudence, have acquired the means for undertaking works of magnitude. This altered state of society would render such exclusive privileges not merely unnecessary, but would make them absolutely pernicious.

Notwithstanding the marked encouragement just related on the part of the French government, some time elapsed before the manufactures of France could rival those of Italy. Venice, in particular, long excelled in the quality of its mirrors and drinking-glasses, with which the manufacturers of that city supplied the rest of Europe. The most considerable of their glass-houses were established at Murano, a village situated a short distance from the city.

During the ministry of the celebrated Colbert, some French artists, who while residing in the Venetian state had acquired a knowledge of the processes used at Murano for the making of plate glass, returned to France in the hope of profitably pursuing the manufacture in their native country. Such an event falling in with the views of Monsieur Colbert, who was anxious by every means to extend the useful arts within the kingdom, these artists were in the year 1665 established with privileges at Tourlaville near Cherbourg, and an advance of money was made to them from the public coffers to assist in the formation of their establishment. The plates made by this company were blown, after the system used in the Venetian manufactories.

It was not until 1688 that the beautiful art of casting plates of glass was invented by a manufacturer named Thevart, who, obtaining a patent for the invention to continue in force during thirty years, established a company and erected works in Paris, where plates were cast of the then extraordinary dimensions of eighty-four inches long by fifty inches wide, a size which excited universal astonishment and admiration. The expense of conducting such a manufactory in the metropolis was, how-

ever, so great, that the establishment was transferred to St. Gobain in Picardy, where the undertaking was prosecuted, not without considerable opposition from the more ancient association.

To accommodate the disputes between these rival establishments, Thevart's company was bound not to cast any plates whose dimensions should be less than sixty inches in length and forty inches in breadth. The largest piece that had then been produced by blowing did not exceed fifty inches in its largest dimension. This arrangement failed to produce harmony between the rivals; but in 1695 that end was effectually answered by uniting both companies under the same charter—not however, as the issue proved, to their mutual advantage; —for, possibly owing to the want of the salutary spur of competition, the company declined in prosperity with such rapidity, that in two years from the junction the united body was in a state of insolvency, obliged to discharge most of its workmen, and to abandon many of its furnaces.

No blame can be charged upon the French government for the protection and privileges afforded to these companies. It is probable that without some immunities neither of the establishments could at that early period have been undertaken. The instances however are rare, and the circumstances whereby they have been attended peculiar, in which joint-stock trading companies have been prosecuted to advantage. The causes of this fact are not difficult of explanation. It is seldom that the personal interest of those to whom the particular management is intrusted is sufficiently strong to insure the requisite amount of attention, or the proper degree of pecuniary watchfulness, if even the still more unfavorable condition does not arise wherein private advantage is opposed to the general prosperity, and it is sought to conduct the operations rather with a view to individual profit than to the common advantage.

In the following year a new association was formed out of the ruins of the old company, under the management of Antoine d'Agincourt, who re-engaged the discharged workmen, and by the prudence of his arrangements conducted the affairs with considerable profit to the adventurers.

Blancourt, in his "Art de la Verrerie," relates as the mode in which the casting of plates of glass was discovered, that a person who was melting some of this material in a crucible accidentally spilt it while fluid upon the ground. The metal ran under one of the large flag-stones wherewith the place was paved, which obliged the workman to take up the stone in order to recover the glass. He then found it in the form of a plate, such as could not be produced by the ordinary process of blow-

ing. The man's attention being roused by this fact, he was unable to sleep; and conceiving at once the superiority of this method for forming mirrors, he immediately commenced experimenting; and before the day appeared had proved the practicability of the improvement which the purest chance had thus placed within the sphere of his observation. This occurrence is said to have arisen 200 years before it was related by Blancourt, whose treatise is dated in 1698. It cannot therefore have any reference to the then recent proposals and performance of Thevart.

The manufacture of flint glass was first begun in England in the year 1557, at Savoy House in the Strand, and in Crutched Friars. In 1635 Sir Robert Mansell obtained a monopoly for making this kind of glass, in consideration of his being the first person who employed pit-coal instead of wood in his furnaces. The art could not at this time have reached any great degree of perfection, as permission was further conveyed by the patent for importing drinking glasses of fine quality from Venice, and another half century elapsed before this country became independent of foreign supply for such articles.

The second duke of Buckingham has the merit of much improving the manufacture of British glass by means of certain Venetian artists whom he brought to London in 1670. Three years later than this period, the first plates of English glass were made at Lambeth under the auspices of the same nobleman. The violence of party spirit which characterized that age should lead us to receive with caution all estimates of character which we may find recorded by contemporary biographers. Although there was unquestionably much of vice and profligacy in the general conduct of this favorite of a vicious and profligate master, we may yet hesitate to believe that the man who could apply himself to the study of letters, and who, in the manner above related, interested himself in promoting the useful arts of life, could at the same time be so utterly depraved both in mind and in heart as the page of history has represented.

The first English establishment of magnitude for the casting of plate glass was undertaken in 1773. A respectable body of gentlemen at that time obtained a royal charter of incorporation, the privileges of which were confirmed to them by act of parliament, under the style of "The Governor and Company of British Cast Plate Glass Manufacturers;" and having subscribed a capital or joint stock in eighty shares of five hundred pounds each, constructed works of considerable extent at Ravenhead, near Prescot, in Lancashire. This undertaking, the only one of the kind existing in this country, and rivalled by

each other, the effect appears in a yet more striking point of view. The annual average quantity made for home use during the three years ending in 1812 was 413,414 cwt., while the average of the three following years ending in 1815 was 264,931 cwt.; showing an immediate falling off of 148,483 cwt., being upwards of 35 per cent. upon the larger quantity; a circumstance which could not fail, among other evils, to bring distress and misery upon a considerable number of operative manufacturers.

On the other hand, a diminution in the rate of duty on plate glass was effected on the 5th of July, 1819, it being then lowered from 98*s*. to 60*s*. per cwt. As a consequence, the quantity manufactured has since been steadily and progressively increasing. During the three years preceding the abatement, the average quantity annually manufactured was 6209 cwt., yielding a gross revenue of 30,424*l*., whereas the average quantity made during the three years ending in 1829 amounted to 15,235 cwt., and the revenue produced was 45,705*l*., being an increase of more than 50 per cent., derived from a rate of duty diminished to the extent of 40 per cent.

Could any facts more forcibly point out the pernicious tendency of heavy duties upon articles of domestic manufacture, or more clearly indicate the course which it were wise to follow in remodelling to as great an extent, and as quickly as is practicable, this branch of our financial system?

It is much to be regretted that any circumstances should have arisen to delay the execution of the expressed intention of the government altogether to remove the duties upon glass. Whenever this measure shall be accomplished, it can hardly fail to induce such an extension of the manufacture as will prove generally beneficial to the community. The abolition of these duties would be accompanied by the still further advantage of removing all those vexatious regulations and restrictions under which the manufacture is now carried on, and which will cease, as a matter of course, when the article is no longer an object of revenue.

It is principally owing to these restrictions that so much foreign glass is now brought into this country in the face of what may be considered an amply protecting duty. Foreign manufacturers are allowed to make any and every article out of that quality of glass which will most cheaply and advantageously answer the end, while our own artists are forbidden to form certain objects, except with more costly materials, which pay the higher rates of duty. Nor is this restriction only commercially wrong, since it forms matter of just complaint on the part of chemists, that they are unable to procure utensils fitted for

effecting many of the nicer operations connected with their science, because the due protection of the revenue is thought to require that such utensils shall be formed out of that quality of glass alone which, apart from all considerations of price, is otherwise, from its properties, really unfitted for the purpose. Relaxations are, indeed, sometimes made on this head in particular cases by the commissioners of Excise; but the trouble necessarily attending applications to a public board is greater than can be compensated by the trifling money advantage that can result in each case to the manufacturer, and the interests of science are, consequently, made to suffer.

CHAP. II.

ON THE VARIOUS INGREDIENTS EMPLOYED IN MAKING GLASS.

Glass always composed of Silex with Alkali.—Different Descriptions of Glass.—Sea-Sand.—Soda and Potash.—Pearl-Ash.—Barilla.—Kelp.—Wood Ashes.—Nitre.—Litharge.—Minium.—Manganese.—Arsenic.—Borax.—Chalk.

UNDER the general name of glass, chemists comprehend all mineral substances, which, on the application of heat, pass through a state of fusion into hard and brittle masses, and which, if then broken, exhibit a lustrous fracture. Most glasses are transparent also; and the non-existence of this property is generally owing to the presence of some foreign and unessential substance.

The glass of commerce—that beautiful manufacture to which the generic name is most commonly applied—does not include so wide a range of bodies; and is always composed of some silicious earth, the fusion and vitrification of which has been occasioned by certain alkaline earths, or salts, and sometimes with the aid of metallic oxides.

There are five different and distinct qualities of glass manufactured for domestic purposes; viz.

Flint glass, or crystal;
Crown or German sheet glass;
Broad or common window glass
Bottle or common green glass; and
Plate glass;

the materials and the processes used in making which form the subject of our present inquiry.

Before commencing the description of any of the manipulations employed in this interesting manufacture, it will be better

to give a general account of the different materials used, and to point out how the particular qualities of glass are influenced by the properties of those various ingredients.

Each of the five descriptions contains, in common with the others, two ingredients, which, indeed, are essential to their formation—silex and an alkali.

The variations of quality, and distinctive differences observable in glass, principally result from the kind of alkali employed, and its degree of purity, as well as from the addition of other accessory materials; such as nitre, oxide of lead or of manganese, white oxide of arsenic, borax, or chalk.

Silex is not equally proper in all its forms for the composition of glass. Sea sand, which consists of spherical grains of quartz, so minute, as to be qualified for the purpose without any preparation except careful washing, is the form wherein silex is most commonly used for the purpose in England. All sea sand is not, indeed, equally applicable to the glass-maker's purpose. That used in this country for making the finer descriptions of ware is usually obtained, either from the port of Lynn, in Norfolk, or from Alum Bay, on the western coast of the Isle of Wight.

The best glass was formerly made with common flints, calcined and ground in the manner already described, as used in the manufacture of pottery, and hence the name which it acquired of flint glass. The employment of silex in this form is now wholly discontinued in glass-houses, as it is known that some qualities of sand answer the purpose equally well, while the labor and expense of calcining and grinding are saved by the substitution.

Both soda and potash are well adapted to the purpose of making glass. They are used in the form of carbonates; that is, holding carbonic acid in combination with themselves as bases. The acid flies off during the progress of the manufacture, and the result is a compound of silex and alkali.

As already stated, the quality of glass is influenced by the degree of purity of the alkali. For making the finest flint glass, pearl-ash, which is potash in a purer form, must be used. The alkali must previously be still further purified by solution and subsidence, and then evaporating the fluid to dryness. By this purification a loss is sustained, amounting to between 30 and 40 per cent. in the weight of pearl-ash. Coarser kinds of alkali, such as barilla, kelp, or wood-ashes, which are combined with many impurities, are employed for the production of inferior glass. Complete fusion and vitrification are accomplished by these means, the impurities even being of a nature to assist towards the production of these effects. The green color imparted to glass, is produced by the iron, which is present in a

greater or less degree in these courser alkaline substances. Barilla, when sufficiently cheap, is always chosen preferably to wood-ashes or kelp. The recent abatement of the import duty levied upon this article of commerce will, therefore, probably tend to the increased consumption of barilla in glass-houses.

A very small proportion of nitre is used in the composition of glass, to occasion the destruction of any carbonaceous matter which may exist in the ingredients. This salt must be added previous to the fusion of the glass. At a degree of heat much below that of the furnace, nitre will decompose, giving out much oxygen, and maintaining such metallic oxides as may be present in their highest state of oxygenation. It is thus of use in fixing arsenic, the volatile property of which increases as it approaches the metallic state.

Oxide of lead, in the form of either litharge or minium, is essential to the making of flint-glass, into the composition of which it enters very largely. This metal acts, in the first place, as a most powerful flux, promoting the fusion of all vitrifiable substances at comparatively low temperatures. It is also permanently beneficial in imparting highly valuable properties to the glass of which it forms a part. This, by its means, is rendered much more dense; has a greater power of refracting rays of light; possesses more tenacity when red-hot, causing it for that reason to be more easily worked; and is rendered more capable of bearing uninjured sudden changes of temperature. On the other hand, glass, into the composition of which much lead has entered, is so soft as to be easily scratched and injured if rubbed against hard bodies. Such glass is also improper as a recipient for many fluids which are of an acrid nature, by which it would be corroded and destroyed. Another great inconvenience attending the use of lead is this, that it does not become intimately enough united with the other components for the whole mass to assume an uniform density. It will almost always happen, that the glass at the bottom of the pot contains a larger proportion of litharge than that above. This inequality of density is continually increasing as the contents of the pot are diminished by the workman; and it is thence impossible to withdraw from it any two portions whose densities shall agree.*

* Mr. Faraday has stated, in his paper on the manufacture of glass for optical purposes, which appeared in the Philosophical Transactions for 1830, that he found, on examining "pots containing glass not more than six inches in depth, made from the usual materials, and retained at a full heat for twenty-four hours," the following differences of specific gravity between the glass taken from the bottom and surface of the pots:—

Top,	3·32	3·30	3·28	3·21	3·15	3·73	3·85	3·81	3·31	3·30
Bottom,	4·04	3·77	3·85	3·52	3·80	4·63	4·74	4·75	3·89	3·74

Monsieur Guyton Morveau has related a very curious exemplification of this fact, which once occurred to himself when experimenting in conjunction with Monsieur de Buffon in the plate-glass manufactory near Langres.* Remaining in the crucible was a portion of flint glass in fusion, composed of thirty-two parts powdered crystal, thirty-two parts minium, sixteen of soda, and one part nitre. To this was added the requisite quantity of the ingredients commonly employed for forming plate-glass in the manufactory, and the whole was melted together in the furnace. When the mass was sufficiently refined it was laded into the cistern, cast on the copper table in the usual manner, and transferred to the annealing furnace. Its quality being subsequently submitted to examination, the plate was found to be composed of two distinct and perfectly level strata through the whole mass, the lower stratum occupying about one third of its thickness.

So complete an instance of the precipitation of the denser through the lighter portion is not elsewhere to be met with in the records of glass-making: its occurrence in this particular occasion should probably be referred to the active agency of some cause which escaped the observation of the two philosophers.

It is a general effect of this inequality, that the glass, when wrought, appears waved; a defect which is particularly inconvenient in that which is intended for the construction of optical instruments. Glass is also fusible at lower temperatures according to the proportion of lead which it contains. This quality, which would be mischievous for some purposes, is, on the contrary, beneficial for others. It is often essential to chemists that they shall be able, during the progress of their experiments, to bend the tubes with which they are operating.

Black oxide of manganese has long been used for clearing glass from any foul color which it might accidentally possess through the impurity of the alkali employed, and in particular from that green tinge which marks the presence of iron. This property of manganese, when in the form of an oxide, occasioned it to be anciently known as *glass soap*, a name which very accurately describes its use. The circumstances attending the employment of this substance in glass-making are of rather a curious nature. When added in a moderate proportion to any simple glass, it imparts a purple color; and should its quantity be much increased, this color is deepened until the glass becomes nearly black. If, while the mass thus colored is still in fusion, either white arsenic, or charcoal, or other carbonaceous matter be added, an effervescence is seen to follow,

* Ann. de Chim. vol. lxxiii. p. 113.

and the color becomes gradually more faint until it altogether disappears, and the glass is rendered clear and transparent. Provided the green hue which it is desired to counteract be considerable, the application of a very small quantity of manganese is not followed by any sensible tinge of purple; but the moment that the proportion is more than sufficient for the purpose, this color immediately appears, and must be corrected. This correction is performed in a very simple manner in the glass-house, by thrusting into the pot of melted glass a piece of wood, which, becoming charred by the heat, causes the purple again to vanish; while a slight effervescence as before described, and the escape of numerous bubbles of air, are plainly perceptible. If nitre be then added, the purple color will be restored.

The reason for these changes it is not difficult to explain. The oxide of manganese imparts a purple color, only when in a state of high oxygenation. When brought into contact with carbonaceous matter, it is partially deprived of its oxygen, and loses its coloring property. The air-bubbles which escape consist of carbonic acid gas, which is disengaged by the action of the charcoal on the oxide of manganese. The effect which follows upon the introduction of nitre is of a contrary nature. When made of a red heat this substance gives out oxygen in great abundance, and the manganese being thus reinvested with the oxygen of which it was deprived by the charcoal, resumes with it the coloring property.

Another advantage attending the use of oxide of manganese results from its property of powerfully assisting in the fusion of earthy bodies. It also gives considerable density to glass, but the same disadvantage accompanies its use as already has been noticed with regard to litharge. Having from its greater specific gravity a tendency to settle towards the bottom of the pot, the glass by this means varies in density throughout its substance, in addition to which circumstance the manganese acts injuriously upon the pots by corroding them at the bottom.

One of the uses of white oxide of arsenic has already been described, that, namely, of correcting the coloring effects of manganese. It is also a very powerful flux, and a great temptation to its use is found in its cheapness. It should, however, be employed with moderation. If a considerable time be not allowed for its intimate incorporation with the other ingredients of the glass, this will appear clouded or milky; a fault which will afterwards increase with the lapse of time. An excessive quantity of arsenic likewise occasions the glass to become gradually soft and to decompose, for which reason the employment of drinking-vessels in this condition is unsafe.

Another, and a harmless, application of arsenic in glass-making is, when it is introduced into the fused mass in order to dissipate any carbonaceous matters which result from defects in preparing the alkali. In this case, small lumps of white arsenic are intimately blended with the mass by stirring. The great heat causes it at once to unite with and to carry off the carbon in a volatile form, leaving the glass entirely free from carbonaceous matter, and nearly so from arsenic.

Borax is used in preparing only the finest descriptions of glass: its employment is, indeed, principally confined to plate glass. It is too expensive to admit of its forming part in the composition of common descriptions, although its use in all cases would be desirable, as its efficacy in promoting the fusion of vitrifiable substances is unrivalled. When the borax has been introduced, the compound is caused by it to flow with great freedom, and to be without specks and bubbles, which would impair both its beauty and utility. Should the alkali employed prove deficient in strength, a small portion of this salt will serve as an effectual remedy.

Lime in the form of chalk is useful as a very cheap flux. It is also beneficial in facilitating the operations of the workman in fashioning glass, and it has the property of diminishing its liability to crack on exposure to sudden and great variations of temperature. Chalk can only be used sparingly, however, in the glass-house, as the escape of carbonic acid causes the ingredients in the pot to swell considerably during the fusion. The presence of lime in any excessive degree would also occasion the rapid destruction of the pots, upon the substance of which it acts with considerable energy. Glass wherein lime exists in excess is also rendered cloudy, although the mass while in fusion appears perfectly pellucid. Not more than about six per cent. of lime can be added without risking this defect.

CHAP. III.

ON THE CONSTRUCTION OF FURNACES, ETC.

Stability of Furnace Essential.—Fritting Furnace, or Calcar.—Its Use.—Working Furnace.—Double Furnace.—Proportionate Dimensions of Furnace and Pots.—Wood-Furnaces.—Comparative Consumption of Fuel in Wood and Coal Furnaces.—Annealing Oven.—Lier-Pans.—Glass-Pots.—Their Formation and Seasoning.

It is essential to the well conducting of the operations of glass-houses that their furnaces should be well and substantially built of the best materials, and according to the most approved construction.

Monsieur Loysel was so deeply impressed with the necessity of devoting the greatest degree of attention to this branch of the art, that nearly one half of his clever treatise "Sur l'Art de la Verrerie" is occupied with its details. This author not only gives instructions for the choice of materials proper for constructing crucibles and furnaces; but also points out the forms which will be found most convenient and advantageous.

In this country, and since the appearance of the work of M. Loysel, those operations connected with the useful arts which depend upon the agency of heat have become much better understood than formerly, so that principles for the right attainment of which it was then necessary for individuals to search and inquire, and frequently even to experiment, are now become matters of every-day practice. It cannot, therefore, be necessary to imitate that author in all his lengthened initiatory directions for the digging and purifying of clay—in his description of the qualities that should determine our selection of this material, or in the detail of mechanical arrangements that will prove most efficacious in giving durability to furnaces.* All these particulars may safely be committed to the skilfulness of the professional builder.

Some other points there are, however, connected with this subject, wherein a greater degree of knowledge than is at present possessed is indeed desirable. To persons who have bestowed the smallest attention upon the phenomena of heat and combustion it can scarcely fail to appear that science has yet an

* In stating the degrees of consistence of the clay most proper for the furnaces in different parts and stages of their construction, Mr. Loysel points out a simple method of ascertaining the attainments of these degrees, which has the advantage of being easily accomplished by any workman. It consists in dropping a leaden ball of a given weight from a determinate height upon the mass, which should be of that density which will allow the ball, by the force of gravitation acquired in its descent, exactly to bury itself in the clay.

ample field for research there open to her investigations, and that the arts have still to look for further and most important benefits at the hand of philosophy.

The whole operations of the glass-house depend upon the stability of its furnaces. In their original structure the prudent manufacturer will, therefore, not hesitate to avail himself of the assistance of the ablest builders, and to employ materials which are best qualified by their density and infusibility for resisting the action of violent and long-continued heat. No present saving in the cost of construction can at all compensate for the expense and interruptions occasioned by the necessity for frequent repairs, and still less for the losses of time, labor, and materials, that would accompany casualties, the chances of which would be multiplied by want of proper attention to the matters here pointed out. An equal, and perhaps even a greater degree of judgment is required for the selection of materials proper to form glass-pots or crucibles, since these have to withstand the action of heat in as violent a degree as any part of the furnace, and are additionally exposed to injury from the solvent property possessed by some of the materials, for the fusion of which they are employed. These pots are therefore made of the most refractory, that is, the least fusible, materials, and are fashioned with every possible attention to their strength.

Three different kinds of furnaces are employed in the manufacture of glass. One, which is called the *calcar*, a name corrupted from the French word *calquaise*, is used for that calcination of the materials to which they must be subjected previously to their complete fusion and vitrification. This process, which is called *fritting*, a term likewise borrowed from the French, is used for various reasons. In the first place, it expels all moisture from the materials, the presence of which would hazard the destruction of the glass-pots. Next it drives off, either wholly or in great part, the carbonic acid gas from the chalk and alkalies employed, by which means the swelling of ingredients in the pots is either prevented, or moderated within safe limits. This calcination has the further advantage of destroying all carbonaceous matters that may be present in the materials. But the principal object of previous calcination is, that a chemical union may be effected, or at least commenced, between the silex, the alkali, and the metallic oxides. Otherwise, at the heat of the working furnace, the alkali would fuse, and its comparative levity would cause it to take its station at the surface, while the other ingredients would subside towards the bottom. The uncombined alkali would, in this case, after acting upon and injuring the substance of the crucibles, be, in great part, volatilized and lost; and a portion of the sand would

remain unvitrified, while the glass actually produced would contain an excessive quantity of silica.

These observations do not apply to the preparation of materials for making flint glass, the fusibility of which is much greater than that of other descriptions, owing to the presence of its large proportion of lead. For this reason, manufacturers of this kind of glass apply the process of calcination to the sand alone, with the view of separating from it all carbonaceous impurities, previous to its admixture with the remaining materials.

The name of fixed alkalies has been given to soda and potash to denote their property of resisting the destructive influence of fire. As they are volatilized freely by subjection to a red heat, this property cannot, however, be strictly ascribed to either of these substances, and the title must be understood only as distinguishing them from other alkaline bodies, which are acted upon by comparatively low additions of temperature.

The calcar is in the form of an oven about ten feet long, seven feet wide, and two feet high. The coal used in heating it is placed in a sort of trough on one side, and the flame is made to reverberate from the crown of the oven back to the frit. In this operation, care is required to keep the degree of heat at all times within that which would melt the materials, and at first below the point whereat the yet uncombined alkali would be volatilized.

The process must not be hurried at first; but after two or three hours the temperature may be gradually raised until the mass becomes pasty. Having been kept in this state during three or four hours longer, it is then removed from the calcar and cut quickly, before it has time to harden, into square cakes. These are piled away for future use. It is the opinion of many glass-makers that frit is improved in quality by age; under which impression some among them so manage their operations as not to bring their store successively to use until it has been prepared for at least twelve months.

The working furnace is that wherein the frit, when placed in the glass-pots or crucibles, is fully melted and converted into glass. These crucibles are deep pots, varying in size according to the objects of the manufacturer, but sometimes large enough for each to contain a ton weight of glass. Twelve of these are usually placed, at regular intervals, in the circumference of each kiln, their only opening being at the side nearest to the wall of the kiln, in which they meet with corresponding openings, so that the pots can be readily charged, and their contents as readily removed, by the workmen who stand in recesses formed by projections of the masonry. The external form of the furnace is circular, rising conically from its base and termina-

ting in a chimney. The interior is dome-shaped, and supported on arches. Flues are constructed under these for the admission of atmospheric air, which, rising through the fire-bars that occupy the centre of the floor of the furnace, the flame and heated air are made to envelop the pots, and thence pass on to the chimney issuing from the centre of the dome.

A very important saving in the article of fuel has lately been effected in one of the London glass-houses, that of Messrs. Pellatt and Co., by substituting for one of the large twelve-pot furnaces they had been accustomed to use two similarly constructed, but having only one half the diameter. The circumference of these two being together equal to that of the large furnace, they are made to contain as great a number of pots, and of the same size, as were formerly employed; while the internal area of the two, being together equal to only one half that of the furnace for which they are substituted, the pots are necessarily brought more than before within the intensest influence of the fire. The same chimney is made to serve for both furnaces, by which means the expense attending the alteration has been much diminished.

Fig. 1.

It is said, that the weekly expenditure of coals has been lessened, by means of this alteration, to the extent of ten chaldrons.

The dimensions of the crucibles and furnace should bear some relation to each other. If the former, from their diminutive size, are much below the efficiency of the furnace, a very needless expenditure of fuel will be the result; and should the

crucibles be too large for the power of the kiln, the heat will not prove sufficient. In this case, an excess of fluxing materials must be used in order to form glass, which will be imperfect, according as it is fused below the most beneficial degree of temperature. The relative proportions of pots and furnace may be somewhat varied according to the power of promoting combustion, which partly depends upon construction and situation. Loysel recommends, that in general the aggregate area of the crucibles should be very little beyond one fourth of the area of the furnace. The experience whereon this recommendation rested was drawn from the use of wood as a combustible, which requires a greater space than coal for the development of a given effect. The difference thus arising would, on the other hand, be lessened by the necessity which we are under for covering the pots; whereas, if the kiln is heated by means of wood, these may remain uncovered, and their contents will, in consequence, be more efficiently acted on by the heat. Loysel states,* as the result of experiments continued during a whole year, that the weight of dry beach wood consumed in a glass-house furnace exceeded the weight of coal burnt in the same furnace, and during an equal period, in the proportion of 45 to 28. According to Lavoisier, the heating effects of wood and coal are in the proportion of 1089 to 600.

The result of Loysel's experiment should consequently have shown similar effects from the combustion of 45 parts by weight of wood, and 24·8 parts of coal; the difference between this last quantity and 28 being, probably, the loss consequent upon covering the crucibles.

The openings already mentioned, as serving for the introduction of the materials into the crucibles, and for the removal of the melted glass, are called *boccas*. These may be closed either wholly or partially, according to the need of the workman, by means of movable collars, or, to speak more correctly, by temporary screens made of fire-clay. On either side of each bocca is a smaller circular opening, sometimes called a *boccarella*, but more generally by the familiar name of nose-hole, the particular use of which will be explained hereafter.

The annealing oven, or lier, is a long, low, rectangular chamber, heated at one end, and furnished with numerous shallow iron trays, which can be passed easily along the level bottom of the chamber. These trays are called *lier-pans*, or *fraiches*; which names, together with those of several implements used in glass-houses, are evidently adopted from the French.

As regards the structure of the annealing chamber, there is nothing that particularly requires notice, or that will not be

* L'Art de la Verrerie, p. 72.

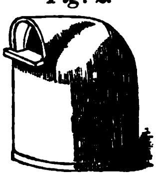
rendered sufficiently clear by the explanation of its use that will be given in the following chapter, while describing, in their regular course, the consecutive processes of the manufacture.

Every glass-house should possess within itself the means of making all the crucibles and other earthen utensils that may be required for its operations. The conveyance of these from any considerable distance would add materially to their cost, not only by the mere expense of carriage, but through the greater liability to fracture, whereto such unwieldy vessels would in that case be subject.

These crucibles, or glass-pots, should be made with five parts of the best Stourbridge fire-clay and one part of old broken crucibles ground to powder for that purpose. Great nicety is required in mixing these ingredients and in working them together, in order to drive out from their substance every particle of air, the presence of which would, by its expansion in the furnace, occasion the immediate breaking of the pots.

The method invariably pursued for kneading the clay is,

Fig. 2.



that the workman treads on it for a considerable time with his naked feet, turning it over from time to time, so that every part may, in its turn, be subjected to the required pressure. An attempt was recently made by a glass manufacturer to employ machinery for the purpose; but after having incurred considerable expense, and exerted much ingenuity in perfecting his apparatus, this gentleman has reverted to the old inartificial method, as being decidedly the best calculated to insure the goodness of his crucibles. This attempt at improvement was not relinquished, until the losses which were sustained in its prosecution became of serious moment.

After the crucibles are formed, they are suffered to remain for a considerable time in the apartment wherein they were made, in order that they may dry equally throughout their substance. It is not, indeed, considered prudent to remove them from this situation until they shall have been formed for at least a twelvemonth.

For some little time before a pot is put to use, it must be placed in an apartment wherein heat can be artificially admitted, and either raised or lowered at pleasure. It is then removed for about three days to a furnace particularly appropriated to the baking of pots; and here the temperature, which at first is moderate, is gradually increased, until at last it is

made nearly as intense as that of the working furnace, for insertion in which the crucible is then sufficiently fitted.

With all the skill and care that can be employed in their manufacture, these crucibles will frequently break during a very early period of their use, and the loss occasioned by that means to the manufacturer is in many ways one of very serious importance.

CHAPTER IV.

ON THE MANUFACTURE OF FLINT GLASS.

The most beautiful and costly Kind of Glass.—Importance of its Quality for Optical Purposes.—Experiments for its Improvement—Undertaken by the Royal Society—Promoted by Government.—Distinguishing Properties of Flint Glass.—To what owing.—Different Compositions.—Process of Melting.—Glass-Gall.—Its Use.—Curious Phenomenon.—Implements.—Collecting Glass on Rod.—Marver.—Paraison.—Blowing.—Re-heating.—Elongating.—Pontil.—Fashioning.—Detaching.—Removal to Annealing Oven.—Moulding.—Annealing.—Why indispensable.—Bologna Phials.—Rupert's Drops.

Flint glass—known in foreign countries under the name of *crystal*—retains among us the title originally imparted by its principal ingredient, although the use of flint in its composition has long since been discontinued.

This glass is the beautiful and peculiarly refulgent compound whereof the finest articles designed for domestic use or for ornament are made. Of all the vitrified compounds that are manufactured, it is the heaviest and the most brilliant; the one most easily fashioned by the hand of the workman, and that which has the greatest refractive power. It is also, from the nature of its constituent materials, the most costly.

Vessels of flint glass cannot, however, be properly applied to all purposes. If, for instance, they are used to contain carbonate of ammonia, they will very soon become so exceedingly brittle, that the very slightest apparent cause will occasion pieces to fall out. Common green bottle glass is not liable to this objection.

Were we to judge from the practice of different manufacturers, in bringing together the ingredients that form this compound, we must believe, that to adhere to any exact proportions is by no means indispensable. In almost every different glass-house a peculiar *recipe* is followed, and no two writers upon the subject agree in their statement of the exact doses wherein any of its components should be used. It is by no means believed, however, that these vague proceedings are without inconvenience, or that some particular compound might not be

discovered and adopted, which, for many purposes, would be superior to every other.

The employment of this species of glass in the construction of optical instruments renders every attempt towards its improvement a matter of universal interest and importance. A committee of scientific men have been for some years engaged, at the expense of government, in a series of experiments, with a view to discover some composition by which glass may be obtained in large pieces, free from those defects which have hitherto circumscribed the power of telescopes within a narrow limit. In such investigations, however, great difficulties are to be encountered; and a long time is as necessary as great talents to overcome them. The progress which has been made by the committee, though not perhaps so great as the lovers of science could have wished, is still as great as the difficulties of the subject—even in the most able hands—would have led us to hope for, and is sufficient to justify sanguine anticipations of future success.

The properties of flint glass which distinguish it from other vitrified substances are owing to the presence of some metallic oxide. All metals, when oxidated, will combine with silica and alkali to form glass. Few of them are, however, properly qualified for the purpose, in consequence of their imparting colors to the mass. The oxides of lead and of bismuth are the only two which may be used in sufficient quantity without producing this inconvenience; and as lead is by much the cheapest of these metals, it is always preferably employed in the manufacture. An over dose of lead will, indeed, discolor glass, imparting to it a tinge of yellow.

It is essential to the goodness of the glass that no impurities or foreign matters should be combined with the lead, and as the adulteration of its various oxides is both easily effected, and difficult of detection, the glass-maker who does not prepare this substance for himself, should make his purchases only from persons on whose probity he can rely. Loysel recommends the use of *minium*, as being less susceptible of adulteration than the other oxides of lead. English glass-makers more frequently employ *litharge*.

The author just mentioned gives as the composition of crystal, where coal is employed as fuel,—

White sand	100 parts.
Red lead	80 to 85
Pearl-ash	35 to 40
Nitre	2 to 3
Oxide of manganese	0·6

Where wood is used for the reduction of the ingredients, and

where consequently, the crucibles may be left uncovered during the process, a different mixture is preferred. In this, a much smaller proportion of metallic oxide is added; and the reason assigned by M. Loysel for this variance is, that the air, having constant and unimpeded access to the surface of the glass, supplies any deficiency of oxygen, while the process is, through the more direct application of heat, more quickly performed, and the glass when manufactured is harder and more durable. The proportions given for this compound are,—

White sand	100 parts.
Red lead	50 to 60
Pearl-ash	30 to 40
Oxide of arsenic	0·75 to 1

The specific gravity of this glass will not be so great as that of the former compound in the proportion of 29 to 32, and its refractive power will evidently be smaller also.

Messrs. Aikin, who, as a matter of scientific research, formerly directed their minds to the consideration of this important branch of manufacture, and who then made many experiments connected with the art of glass-making, state* that a very excellent article may be made from—

120 parts fine clean white sand;
40 —— well purified pearl-ash;
35 —— litharge or minium;
13 —— nitre, and a small quantity of the black oxide of manganese;

the superior fluxing power of the nitre supplying, in that respect, the difference which exists in the proportion of lead between this compound and the first formula of Loysel. To introduce so large a dose of metallic oxide as is recommended by the French author produces an inconveniently soft material. That the proportion is excessive may well be inferred from the fact ascertained by Dr. Priestley, that if a tube of glass so compounded be made red-hot, and a stream of hydrogen gas be passed through it, the whole inner surface will be covered with a half brilliant black substance, which results from a partial reduction of the lead, and moisture will appear at the further end of the tube.

The result of many preliminary experiments made on a recent occasion by Mr. Faraday, with the object of producing perfectly homogeneous glass for optical purposes, induced that gentleman to give the preference to a compound of silica, boracic acid, and oxide of lead, brought together in single proportionals, and which he therefore designates a silicated borate of lead.

* Dictionary of Chemistry, vol. i. p. 496.

The important aim of Mr. Faraday's inquiries induced him to neglect no one particular by which they could be forwarded, and he accordingly employed all those chemical means with which he is so perfectly acquainted to insure the absolute purity of the ingredients which he thus selected.

The oxide of lead was converted from the state of litharge into a nitrate by first washing it and separating the carbonaceous and ferruginous particles, and then placing it in a clean earthen vessel, and dissolving in dilute nitric acid, so as to form a hot saturated solution. After 18 or 24 hours the crystals which had formed were collected, broken up into small particles, and repeatedly washed in fresh clear portions of the mother liquor, in order to remove any insoluble deposited matter. When thus perfectly cleaned, the broken crystals were drained, and then dried by being placed in a sand bath and constantly stirred, after which they were preserved in glass bottles for future use.

Mr. Faraday was enabled to procure pure boracic acid in crystals from the manufacturers, subjecting it in every case, however, to careful examination, and testing it by various agents to ascertain the absence of impurities.

Sand from the coast of Norfolk needed no other preparation to insure its purity than to be well washed and calcined, and this was the only source whence Mr. Faraday drew his supply of silica.

The previous fritting described in the last chapter was formerly performed for the manufacture of all kinds of glass; but, as regards the kind under description, is not now adopted. The materials are used in a state of greater purity, and the process is, on that account, as well as for another reason already given, no longer considered advantageous.

The ingredients having been intimately mixed, are cast, by means of clean iron shovels through the side openings, into the crucibles; which, previously to this, must be brought to a white heat. The pots are filled at once with the mixture; but as the bulk of this decreases materially in melting, a fresh portion must be added when this effect has been produced; and this operation is repeated until, by these successive fillings, the vessels at length become fully charged with melted glass. Before any fresh portion of materials is added, that already in the crucible must be completely melted. When this is full, the opening through which the charge was introduced is materially lessened with wet clay, so that only a narrow hole remains, through which the impurities may be removed, and small portions of the contents may, from time to time, be drawn for examination.

Immediately upon the materials being placed in the crucibles, the heat of the furnace is raised to its highest point. The contents are soon observed to sink down in the state of a soft paste, and ere long become perfectly melted. The glass does not, however, immediately thereupon appear transparent, but loses its opacity by slow degrees, as a white porous scum, known by the name of *sandiver* or *glass-gall*, rises through the mass and is removed. This scum appears to consist of salts, which more or less exist in alkalies, and which salts, having little or no affinity for silex, and being specifically lighter than glass, rise to the top. Another foreign substance is sometimes found at the bottom of the pots, and is removed when the glass is worked off. This, which is also called sandiver, is of a nature altogether different from the scum before mentioned, being a vitrified mass of metallic and earthy impurities. In the strong heat of the furnace glass-gall is exceedingly volatile; so that, if not removed as it forms on the surface, it would all be dispersed in the form of a dense vapor, very dark at first, and growing white by degrees, as the glass becomes purer. This vapor is very corrosive, and acts injuriously upon the tops of the crucibles.

Sandiver is purchased by refiners of metals, who use it as a powerful flux. It is necessary that the whole of this substance should come away before the glass is withdrawn from the pots for use, otherwise articles formed with it will appear cloudy, and filled with bubbles. A very strong and long continued heat is generally required before the whole impurities are discharged. As the process advanees, the glass proves increasingly flexible, heavier, and less brittle, till at length the glass-gall is altogether thrown off, no more vapors rise, the bubbles expand, rise to the surface and burst, and the whole is seen to be colorless and translucent.

In this state, vitrification is complete, bat the glass is too fluid to be fashioned, and for this purpose its temperature must be lowered by stopping the draught of the furnace in that particular part where the crucible is placed; the clay wherewith its opening was lessened is then removed, and the operations of the glass-blower may be commenced.

When cooled to the heat most proper for its being wrought, the glass has lost its perfect fluidity, being of a consistent and tenacious mass, soft enough to yield to the slightest external impression, yet capable of being bent, pulled, and fashioned into all imaginable shapes, without cracking or parting with its tenuity; so that if in this state it be stretched or drawn out, it will preserve the form of a solid fibre, constantly decreasing in its diameter, and will not separate until reduced to the merest fila-

ment. When no longer heated to redness, glass becomes rigid, brittle, and transparent. During the whole time employed in working a pot of glass, which varies from five to twenty hours, and is sometimes even longer, its consistence should be maintained as nearly as possible at the same point, and to succeed in this calls for considerable attention on the part of the workmen.

The contents of all the crucibles do not come into the working state at the same moment; but no injury arises from this cause, as glass may remain for a very considerable period in the melted state without, in any respect, altering its qualities. The fusion and perfect refining of flint glass, as here described, are usually completed in about forty-eight hours from the first charging of the crucibles.

In the operations of a glass-house it is, indeed, common, purposely to manage the vitrifying of the materials so that the contents of the different crucibles shall be brought to the state proper for blowing in succession, that when the glass contained in one is all worked up, that in another shall be in perfect readiness for use. By this arrangement the workmen experience no interruption, and the heat of the furnace is constantly maintained, which last is a consideration of some importance; for if through any accident, the temperature be allowed to sink in a material degree, considerable expense of time and fuel are required for its restoration.

It is by no means advisable to employ in the formation of the same glass vessel materials drawn from more than one crucible. Although the original composition may have been altogether identical, and the fusion of all has been simultaneously carried forward in the same furnace, still a minute difference may, and generally will, exist in the constituent proportions of each mass, arising from an accidental variance of draught, and consequently of heat, in different parts of the furnace, whereby some crucibles may have been made to part with a larger proportion of their alkali than others. Any circumstances which interfere with the perfect sameness of quality in every part of vessels formed of glass renders them more liable to break on exposure to sudden changes of temperature, by reason of their differing tendencies to expand and contract under such circumstances.

The implements used by glass-blowers are few in number, and exceedingly inartificial in their form and construction. The principal one is simply a hollow iron rod or tube, about five feet long, upon one end of which the workman collects the quantity of melted glass that will suffice for forming the article intended. In this operation the rod is dipped into the pot and

turned about several times. If the size of the vessel requires a considerable weight of glass for its formation, the rod is taken

Fig. 3.

out and exposed momentarily to the current of air, by which means the surface of the glass already collected is sufficiently cooled for a fresh portion to adhere, and this proceeding is repeated until enough is collected for the object.

When the rod thus loaded is withdrawn from the crucible, it is held for a few seconds in a perpendicular position, the end to which the glass is attached being nearest to the ground, that by its own weight the mass may be lengthened out beyond the rod. The next operation is to roll the glass on the flat surface of a smooth horizontal iron plate called the marver, a name corrupted from the French word "*marbre.*" By this means the particles of glass are agglomerated in a cylindrical form, which is then called by the workmen a *paraison.* The workman then applies his mouth to the other end of the tube, and blows strongly through it, so that his breath, penetrating the centre of the red-hot glass, causes it to be distended into a hollow globe. The pressure of the breath must be continued upon the tube for a few seconds to prevent the return of any portion of the air

Fig. 4.

through the tube, otherwise the external air being more dense than the heated portion confined within, the globe would collapse: when it has been somewhat stiffened by cooling, this accident is no longer to be apprehended.

The globe, which is not made sufficiently thin by this one blowing, is then heated anew by being held a little within the opening of the furnace; the breath is again employed as before, and so on repeatedly, until the proper size and thickness of the globe are satisfactorily attained.

If the form of the intended vessel requires the globe to be elongated, this effect is produced by giving to the rod, while the glass attached to it is softened by heat, an alternating motion similar to that of a pendulum, or by dexterously making it perform a circle swiftly through the air. The tendency to fly off from the centre which is thus imparted causes the particles to change their relative positions in a degree corresponding with the amount and duration of the force employed.

At this stage another implement, called a *punt*, or *pontil*, is brought into use. This is a solid iron rod of a cylindrical form,

Fig. 5.

smaller and lighter than the tube used for blowing, and consequently more within the power and management of the workman. Upon one end of this rod a small portion of melted glass is collected, by an assistant, from the crucible, and in this state is applied to the surface of the globe on the side opposite to that where it is already attached to the tube. The two heated substances speedily uniting, the glass is detached from the hollow

Fig. 6.

rod, by touching it near to their point of contact with a small piece of iron wetted with cold water. This occasions the glass

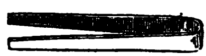
to crack, so that by giving a smart stroke to the hollow rod, it is immediately and safely separated, leaving a small hole at the point of rupture.

The workman now receives from his attendant the pontil with the glass vessel attached, and after reheating it at the furnace mouth as before, seats himself on a sort of stool provided

Fig. 7.

with arms sloping forward, whereon the pontil is supported before him in a horizontal position, the glass being at the man's right hand. Thus placed he governs with his left hand the movements of the pontil by twirling it to and fro along the arms of the stool; and taking in his right hand an iron instrument, called a procello, the blades of which are connected together by an elastic bow, in the manner of a pair of sugar-tongs, he enlarges or contracts the vessel in different places until it assumes the requisite form. Any superabundance of material is cut away by the scissors while the glass is red-hot, with as much ease as they could be made to divide a piece of soft leather.

Fig. 8.



If the article is of a kind, by its size or by the complex nature of its form, to occupy much time in its manufacture, it must occasionally be reheated, as its increasing rigidity makes it more difficult of management.

To insure the requisite regularity in shape and size, the workman is provided with compasses and a scale marked off in feet and inches.

The finished article is detached from the pontil in the same manner as it has previously been from the blowing tube, by wetting it at the point where it is attached, and is then dropped gently on a bed of ashes kept at the man's side for the purpose.

It is then taken up on a pronged stick, or, when from its shape this mode is inconvenient or impracticable, the glass is made to rest during the detaching process on a wooden shovel, wherein it consequently remains when divided. In either case a boy in attendance conveys it without loss of time, and while yet exceedingly hot, to the annealing oven.

If it be required to give to the article any form or pattern which is unattainable by the simple means narrated, a mould is provided, into which the glass is placed while it is being blown, and where it receives the requisite impression with as much facility and faithfulness as wax.

The process of annealing is one of very great importance; without it, glass would be liable to fly with the smallest change of temperature, and would break with the merest scratch or touch, or even without any apparent external cause of injury. The most reasonable theory which has been proposed in explanation of this disposition in unannealed glass is, that by its sudden cooling the external particles are forcibly contracted, while the inner substance still remains soft and expanded. The two portions thus take up positions, in relation to each other, very different from those which they would occupy if the contraction of the whole had gone forward equally and gradually. By this means a constant strain is kept up between the different parts, and should a force be applied of a nature to rive any the smallest portion asunder, the equilibrium of resistance is deranged, and the elastic quality of the glass causes the injury to be felt strongly and suddenly, but very unequally, through the whole mass.

This theory appears to receive confirmation from the well known and often repeated experiments made with the Bologna phial and with Rupert's drops. The first is a phial of ordinary shape made of any kind of glass, much thicker at its bottom than in its upper portion, and which has been suddenly cooled in the air. This phial, from its thickness, will sustain a considerable blow from any blunt instrument, or will bear uninjured the sudden concussion caused by the fall of a leaden bullet. But if any hard and angular substance, such as a minute portion of gun flint or even a grain of sand, be dropped into it, the bottom will crack all round and drop off. In performing this experiment, if the glass be very brittle and the substance dropt upon it be very hard and sharp—a cut diamond for instance—this has been seen to pass through the thick bottom with apparently as little resistance as would be offered by a cobweb.

The greater comparative thickness of the bottom is an indispensable quality of these Bologna phials, and the more consid-

erable this disproportion is made, the more easily will the disruption be effected. Some of these vessels have been struck by a wooden mallet, and were uninjured, notwithstanding the force applied was sufficient to drive a nail into most kinds of wood; and yet the glasses broke readily when a small shiver of flint weighing only two grains was gently dropt within them. Flint being very hard, and its angles when fractured extremely sharp, its points of contact with the glass are exceedingly small, so that the effect produced by even so very minute a portion of this substance will be comparatively greater than would accompany the blow given by a much larger but softer and less angular body, and which for these reasons would divide the shock between a greater comparative number of particles of the glass.

Another theory has been proposed in order to account for this singular property in certain forms of unannealed glass. It has been imagined that the sudden cooling of glass may occasion it to be more electric than is consistent with the cohesive attraction of its particles, and that the sudden setting in motion of the electric fluid which glass contains, may occasion throughout the substance a propagation of the motion of that fluid, which will go on accumulating within itself a force too great to be at length resisted.

This theory is by no means free from difficulties, yet it seems to derive support from a fact which was developed in the course of some experiments made before the Royal Society, in which glass vessels, the thick bottoms of which were only slightly rubbed by the finger, broke after the interval of half an hour had occurred from the time of rubbing.

Rupert's drops are small solid pieces of common green glass, which have been dropped while red-hot into cold water, and which are thus caused to take the form of rounded lumps elongated into a kind of tail. The spherical part will bear very rough treatment without injury; but if the smallest portion of the tail be broken off, the whole article instantly bursts into a countless number of fragments, so minute as to produce only a slight stinging sensation in the hand by the sudden disruption. If one of these drops is immersed in a phial or tall glass filled with water, and its end be broken off with a pair of pincers, the bulb will be rent so suddenly and with so great a force as will infallibly break the vessel wherein it is contained. The stoutest wine or beer bottle would not be strong enough to withstand the shock.

Messrs. Aikin completely destroyed this property in drops of this kind and in Bologna phials, by heating them to redness and then allowing them to cool gradually as in the annealing oven.

Not only was their quality of bursting corrected by this treatment, but the particles of glass were made to assume a closer union among themselves, which fact was proved by the acquirement of a sensible increase in their specific gravity.

The internal form of an annealing oven has been already described. Articles newly made are placed on the shallow trays

Fig. 9.

previously mentioned, in the part of the oven most exposed to the heat of the fire, which, it will be remembered, is kindled under one end only. Each one of these lier pans or fraiches, as it is filled, is pushed forward in the oven, towards the colder end, to make place for a fresh tray, until the articles, at length and in succession, reach the farthest extremity of the oven, whence they are taken, but little warmer than the temperature of the atmosphere.

By the gradual manner in which they have parted with their heat, time has been allowed for the regular contraction of the whole into an uniform and consistent substance.

In glass-houses where objects of various magnitudes and descriptions are made, two or more of these annealing ovens are usually attached to each working furnace. Pieces which are large, and of considerable substance, require that the oven in which they are annealed should be made much hotter than is necessary for thinner and smaller pieces. Glass which is afterwards to pass through the hands of the cutter is always made of considerable thickness, and requires not only that the heat of the oven should be very considerable when it is first inserted, but that it should be withdrawn from this heat very gradually; while, on the contrary, such articles as are very thin may be placed at first in a much more moderate temperature, and may be removed altogether at the expiration of a few hours.

It is impossible by written explanations to impart beyond a very faint idea of the truly curious and interesting operations of the glass-blower. This difficulty does not arise from any complexity in the manipulations. Although, in common with nearly all the manual arts, these call for long practice to insure proficiency, they are yet exceedingly simple in their nature. But there is something more than ordinarily striking—perhaps, even, it may be said fascinating—in watching the progress through which a substance, in its usual state rigid and brittle to a proverb, passes, by rapid conversion, from a glowing and shapeless lump to a perfect article of most elegant manufacture. The absolute control which the workman exercises over its form and substance; the perfect ease and security wherewith he pulls, and twirls, and divides, and joins, a matter which we are accustomed to handle with only gentleness and care; never fail to excite a high degree of admiration even in those who have had frequent opportunities for witnessing the processes.

The amusement to be derived from watching the operations employed in many branches of manufacture is probably much greater than would be imagined by persons who have not so indulged their curiosity; and among these manufactures, although there are doubtless many that call in a higher degree for our admiration as proofs of the genius and perseverance of man, there is not one calculated to afford, for the time, more gratification than the operations of a glass-house.

CHAP. V.

ON THE MANUFACTURE OF CROWN GLASS, BROAD GLASS, AND BOTTLE GLASS.

Description of Crown Glass.—Harder than Flint Glass.—More difficult to Fashion.—Its Composition.—In France.—In England.—Fritting.—Cullet.—Refining.—Sulphate of Soda.—Vegetable Charcoal.—Gathering.—Blowing.—Reheating.—Flattening.—Transferring to Pontil.—Twirling.—Expanding.—Opening.—Annealing.—Nice Regulation of Temperature required in this Process.—Qualities of Crown Glass.—German Glass.—Broad Glass.—Inferior to Crown Glass.—Its Composition.—Preparation.—Working.—Bursting.—Opening.—Annealing.—Bottle Glass.—Manufacture checked by Increase of Duty.—Composition.—Restrictions as to Materials.—Their bad Tendency.—Superiority of Bottle Glass for certain Purposes.—Materials employed in France.—At Newcastle.—Fashioning.—Moulding.—Experiments suggested by Count Chaptal.—Klingstein.—Volcanic Granite.

The name of crown glass is given to the best kind of glass commonly used in making windows, and for like purposes. In the composition of this material, no lead or metallic oxide en-

ters as a fluxing agent. A small quantity of manganese is frequently used, and sometimes also a minute portion of oxide of cobalt; but the object of these additions is the correction of a faulty color in the glass, arising from impurities in the sand and alkali. This kind is, therefore, much harder than flint glass, and would consequently be more difficult to fashion, if it were desired to give it any other form than that of a plane surface.

The composition of crown glass varies considerably. Loysel has given several different recipes for its formation. That which he most recommends, stating that it is employed at the extensive works of St. Gobain, consists of

Fine white sand	100 parts.
Carbonate of lime	12
Carbonate of soda, calcined,	45 to 48
Clippings of crown glass . .	100;

with such additions of manganese and oxide of cobalt, as may be required to correct impurities and remove the color which they occasion. By proper carefulness in selecting and purifying the ingredients, the employment of these metallic bodies is rendered unnecessary.

Crown glass is generally made in France of 100 parts of fine white sand, 50 to 65 parts potash, 6 to 12 parts dry slaked lime in powder, and from 10 to 100 parts of broken glass of similar quality: this composition is frequently employed in that country for the manufacture of common drinking vessels, as well as of window panes.

In England, this material has usually been composed of fine Lynn sand, kelp, and slaked lime; the proportions of these ingredients varying according to the quality of the kelp, some kinds of which contain a greater amount of alkali than others. That from Orkney is considered to be the best, not only on this account, but also because the glass which is made of it proves of a better color than where Scotch or Irish kelp is employed. The proportions when the kelp is of the best quality are,

Fine sand	5 bushels or	200 pounds' weight,
Ground kelp .	11	330
Slaked lime		15;

which ingredients are fritted in the calcar as already described, preparatory to their fusion. When put into the crucible, about half its weight of broken glass, or, as it is called in the manufactory, cullet, is added to the frit. This compound requires to be kept in fusion at a high degree of heat during thirty-five to forty hours, in which time an intimate union of all the parts takes place; the glass refines itself by throwing off all its sandiver, and becomes perfectly transparent. It is not advisable to use a larger proportion of broken and refuse glass than that

just mentioned, because, by its long exposure to heat when in fusion, glass is made to give up a portion of its alkali, becoming harsher and less fusible. The quantity of glass usually employed is serviceable by sooner bringing the pot to a working state; but any larger quantity would, for the reason just stated, sensibly alter the quality of the whole contents of the crucible. The fragments, before they are used, are first heated, and then suddenly plunged into cold water, which renders it easy to reduce them to powder.

A very superior quality of crown glass is made by the mixture of

120 parts by weight of White sand,
60 . . . . . Purified pearl-ash,
30 . . . . . Saltpetre,
2 . . . . . Borax,
1 . . . . . Arsenic.

If the color should prove yellow, this is corrected by the addition of a small quantity of manganese.

Another composition, cheaper than the foregoing, consists of

120 pounds of White sand,
50 . . . . . . Unpurified pearl-ash,
20 . . . . . . Common salt,
10 . . . . . . Saltpetre,
4 . . . . . . Arsenic,
and 3 ounces of Manganese.

This produces glass of a good and useful description, much employed in the manufacture of apothecaries' vials.

The late M. Gehlen, who was well experienced in the art of glass-making, composed crown glass of the following materials*:—

Sand	100 parts.
Dry sulphate of soda . .	50
Quick-lime in powder .	17 to 20
Charcoal	4.

In this case the sulphuric acid in combination with the soda is decomposed by the charcoal, and driven off during the fusion, leaving the soda to unite with the sand. M. Gehlen made many experiments to ascertain the effects of various combinations with sulphate of soda, and found that this salt could be used without the addition of any other saline flux. If mixed with only sand, the vitrification was very imperfect even after long-continued heat. The addition of lime caused it to succeed better, but the time and fuel required were still excessive. When, however, by the addition of vegetable charcoal, the sul-

* Annales de Chimie et de Physique. Fevrier, [illegible]

phuric acid was decomposed, and the powerful affinity destroyed, which prevented the soda from acting on the sand, vitrification was produced both perfectly and quickly. If used in any other proportions than those above mentioned, M. Gehlen found that the fusion was accompanied by disagreeable sulphurous odors, and by an extraordinary swelling over of the materials. The decomposition of the sulphate of soda may be effected with equal advantage, either during or before vitrification, according as the choice of the manufacturer may be influenced by local circumstances.

When the materials are properly fused and refined by the removal of all the glass gall, the workman commences his blowing operations in exactly the same manner as has already been described in the process for making flint glass. By repeated dippings of the iron tube into the crucible, he gathers as much glass upon its end as experience teaches him will suffice for the formation of a sheet of glass of the usual size, and which generally weighs from ten to eleven pounds. This lump he allows to project beyond the extreme end of the tube; and first rolling it on the iron plane before described, to give the glass a cylindrical form, he commences blowing, when it assumes the shape of a pear. A fresh heating and a second blowing enlarge its dimensions, and render its shape more globular. A third operation of heating and blowing still further enlarges the size of the glass, and reduces its substance. The side opposite to the tube is then flattened by pressure against a plane

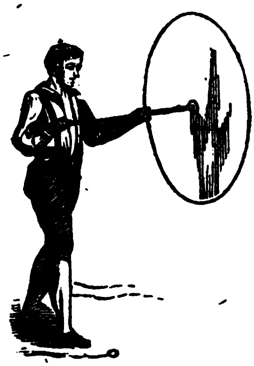
Fig. 10.

surface; a small portion of melted glass is collected on the end of a punt, and is applied to the centre of this flattened side, forming an union with it exactly opposite to the hollow tube,

which is then removed by wetting the glass near to their point of union, leaving a circular hole in the glass about two inches in diameter.

At this period the glass must be again held to one of the openings of the furnace until it has become sufficiently hot and ductile for the further alteration of its shape. The workman then dexterously twirls the punt in his hand, slowly at first, and then more and more quickly, when the glass yields to the centrifugal impulse; its diameter becomes greater and greater; the hole just mentioned expands proportionally; and when in this continued progression the doubled portion opposite to the iron rod, and between the periphery of the glass and the orifice, is diminished to an annulus or ring only a few inches wide, this in an unaccountable manner instantly flies completely open, and the glass is converted into a plane disc of fifty to sixty inches diameter, having an uniform thickness throughout the entire plate, with the exception of the spot where it is attached to the iron rod, and where there is a knot

Fig. 11.



or lump which is called a *bull's eye*. Twelve of these plates make up what is called a crate or side of glass.

The effect of this operation upon persons who witness it for the first time is both pleasing and surprising in a high degree. The force wherewith the glass flies open at the close of the process would be sufficient, if its brittleness were not removed by heat, to break it into innumerable fragments.

The plate, when thus finished, is detached from the iron rod by the usual method, and placed resting on its edge in the an-

nealing oven. Some considerable care is necessary for regulating the temperature at this stage; for if the heat be too great, the [illegible] glass will bend, and for that reason will be lessened in value, while, if the oven be not sufficiently hot, the plates are very likely to crack; and if even this disaster should not happen, the glass will prove of inferior quality, and so brittle, that the glazier will be unable to cut it with any degree of certainty in the wished-for direction.

Crown glass is sold, according to its quality, under four different denominations—firsts, seconds, thirds, and fourths—at considerable difference of price; that of the fourth quality not yielding to the manufacturer nearly one half of the price of the first. These variations arise principally from the want of [illegible] on the part of the attendants, in maintaining the necessary degree of heat in the furnace. If this is once suffer[illegible] glass in being a very imperfect con[illegible] difficult again to raise it to the former [illegible] large glass-house, it does not [illegible] one third of the quantity made is of [illegible] composes the largest propor[illegible] seldom occurs that the quality [illegible] denominations.

[illegible] glass such as are required for glazing [illegible] be imported from Germany. [illegible] for a long time, been not only in[illegible] of all foreign manufacturers, but [illegible] exported to a considerable [illegible]

[illegible] description of window glass, [illegible] a somewhat different pro[illegible] described. The material [illegible] purpose is soap-boiler's waste. [illegible] consisting of the insoluble mat[illegible] lime which has been used [illegible] with a quantity of salt [illegible] with lime and sand, and [illegible] The proportions wherein the [illegible] according to the quality [illegible] manufacturer must be [illegible] quantities.

[illegible] soap-boiler's waste. [illegible] sand. The quality [illegible] to the [illegible] imagined. [illegible]

this, the glass when [illegible]
larger proportion [illegible]
pated and lost during [illegible]
which would injure [illegible]
out, and the [illegible]
after the [illegible]
moved with [illegible]
are entirely [illegible]
to the proper degree [illegible]

The formation [illegible]
The necessary [illegible]
iron tube [illegible]
break [illegible]
twelve inches [illegible]
done, the glass [illegible]
of the tube [illegible]
closed, the further [illegible]
the glass [illegible]
tile, [illegible]
length [illegible]
ing over.

More than [illegible]
Great Britain [illegible]
quantity of [illegible]
an average of [illegible]
However [illegible]
than the annual average [illegible]
mencing in [illegible]
traordinary [illegible]
years our population [illegible]
comforts [illegible]
in the reach of [illegible]
men: and [illegible]
been very considerable [illegible]
rate of duty [illegible]
sufficient for [illegible]
article so generally [illegible]
rate, has never [illegible]
A more minute [illegible]
without any [illegible]
rate of duty, [illegible]
to this branch of [illegible]
duty was 4s. [illegible]
of common bottle glass [illegible]
the succeeding year [illegible]
imposed, the consumption [illegible]

8000 tons. From this extreme depression it has since gradually risen, through the increasing numbers and improved condition of the community, and aided by a diminution of price, independent of the duty; but even now the manufacture has not reached within 2500 tons of the point which it had attained in the year 1812; thus in a very striking manner verifying the remark so often made as to the variance between common and legislative arithmetic, and proving the pernicious tendency of taxes levied upon articles of domestic manufacture. It is to be hoped that the improvement of the national revenue consequent upon the progressive state of our manufacturing interests, and the constantly ameliorating circumstances of many classes of the community, will enable the government to carry speedily into effect a measure already announced for abolishing entirely the duties upon glass of home fabric, when this branch of the manufacture will assuredly receive an impulse that will carry it far beyond the highest point to which it has ever yet attained.

The composition of bottle glass is as little uniform as that of any other description of the material; varying greatly in different parts of the kingdom, and indeed in almost every individual manufactory. It is usually made of sand, lime, and sometimes clay, any kind of alkali or alkaline ashes which may happen to offer the greatest inducement in point of price, and sometimes the vitreous slag produced from the fusion of iron ore Soap-makers' waste is frequently used in the proportion of three measures to one measure of sand.

The rate of duty upon this description of glass being only one eighth of that levied upon flint glass, the manufacturers are restricted to the use of the commonest kind of sea or river sand, lest the revenue should suffer by the superior quality of this less burdened ware. This is unfortunate, since, for the reason already given, the employment of such coarse sand occasions the necessity for using a large portion of alkaline matter, and, in that respect, increases the charges to the glass-blower. The impurity of the alkali, and the abundance of fluxing materials of an earthy nature, joined to the very high degree of heat at which they are fused, occasion the glass to contain a very small proportion of real saline matter; for which reason it is better qualified than flint glass to be employed as the recipient of fluids which have any corrosive action. Chemical retorts and subliming vessels, and carboys for containing aquafortis, should, for this reason, be always made with this common glass, which has this further advantage over flint glass—that it will bear a much stronger heat without being softened or undergoing any alteration of its shape.

Bottle glass is a very hard and well vitrified substance, and is of less specific gravity than other descriptions. Loysel gives, as the composition usually employed in France for the production of this material,—

Common white or yellow sand . .	100 parts.
Coarse kelp	30 to 40
Lixiviated earth of ashes	160 to 170
Fresh wood or other ashes	30 to 40
Yellow clay, or brick earth . . .	80 to 100
Broken glass *ad libitum*, usually	100;

which composition does not produce any glass gall.

At Newcastle upon Tyne, where the manufacture of bottle glass is much encouraged by the excessive cheapness of small coal, or slack, the manufacturers employ a mixture of lime and sea sand. This must be frequently wetted with sea water, which, on evaporating, deposits its salt; the soda contained in this being the only alkali employed. When combined with silica, and exposed to a high degree of heat, lime appears to be endued with the property of decomposing common salt; its presence is, therefore, essential to the success of this operation.

Articles made of bottle glass are fashioned by the same process as those of flint glass, with the exception of wine and beer bottles, the containing parts of which are blown in metallic moulds, in order to keep them nearly of an uniform size. The green color of this glass is owing to the presence of a portion of iron in the sea sand, and, probably also, in the vegetable ashes of which it is composed.

If, during the time when the workmen are employed in moulding and blowing bottles, the melted glass should—as indeed it frequently will—become cooler than is desirable for the purpose, so that it is found necessary to replenish the fire, so much dust will be thus occasioned, owing to the description of coal employed, that the surface of the melted glass will be covered with carbonaceous matter. The effect of this upon the contents of the crucible is very curious. The glass, which had before remained perfectly quiet, becomes suddenly so disturbed throughout as to present the appearance of violent ebullition, and the whole mass is immediately crowded with an infinite number of minute air-bubbles, which, so long as they are suffered to remain, render the glass wholly unfit for use.

The time that would be required for burning away this carbonaceous deposit, and to restore the glass to its former working state, would be so considerable, that it would be highly inconvenient to wait for the production of this effect; and it is therefore fortunate that a simple remedy has been discovered, which

immediately and perfectly restores every thing to its former state.

Whenever the accident here mentioned occurs, the workman has only to throw a small quantity of water into the crucible, when the whole mass will be immediately stilled, and the bubbles will as instantly disappear, so that the workman may proceed without further delay. This curious effect has been referred to the decomposition by heat of the water, which, giving up its oxygen to the coal-dust, converts it into carbonic acid gas; in which form it is instantly driven off by the excessive heat of the furnace, and is dissipated in the atmosphere.

In 1780, the celebrated M. Chaptal recommended M. Ducros, a manufacturer of bottle glass, to make trial of a new material for his purpose. This gentleman entered in consequence upon various experiments, which were, many of them, to a certain extent, successful. The substance thus recommended, and which formed the basis of these experiments, was decomposed, pulverulent, basaltic earth. This is found in great abundance in many parts of France, and is equally obtainable in the valleys of all basaltic countries.

In the first trial made of this earth by M. Ducros, it was fused in a glass pot without admixture with any other substance; and the result obtained was glass of an exceedingly deep yellow color, and lustrous. In subsequent experiments, various proportions of sand were used in conjunction with the basaltic earth. The mixture that was found to answer the purpose best was where equal parts of each ingredient were employed. This produced glass of an olive green color.

There was for some time a considerable demand for bottles thus composed; but owing to a difficulty which the manufacturer experienced in procuring materials having the requisite uniformity in their constituent parts, the manufacture was, after a time, abandoned.

M. Alliot has published the results of a course of experiments made by him with basaltic earth, with a view to the composition of glass. Not being able to have recourse to the furnace of a glass-house, M. Alliot was obliged to content himself with the less intense heat of a potter's kiln, wherein the different mixtures which he employed were severally heated during eighteen hours. It is probable that the results which he has detailed would have proved more satisfactory, could recourse have been had to a more efficient mode of heating. The experiments were all conducted in crucibles.

No. 1. was filled with the pure basaltic earth. This, in fusing, was converted into a black glass, which was opaque, and tolerably well melted.

No. 2. contained a mixture composed in equal parts of basalt, ashes, and white quartz in powder. This produced a coffee-colored glass, which was lustrous, and somewhat resembled porcelain in appearance.

No. 3. was charged with half basalt and half common sand. The glass produced from this compound appeared, when in the mass, of a blue-black color; but when small thin portions were examined, these proved of a yellowish green. This glass was tolerably well melted.

No. 4. consisted of one third each basaltic earth, sand, and refuse soda. The result was a transparent glass of a greenish yellow color, and of good quality; it was very smooth and shining, well melted, and would have formed excellent bottles.

No. 5. consisted wholly of sand taken from the river Orb, in the immediate neighborhood of which there is found a considerable quantity of basaltic earth. The glass from this sand was well melted, and appeared to be every way adapted for the manufacture of very good and serviceable glass bottles.

This basaltic earth is exceedingly well qualified both for fusion by itself, and for employment as a fluxing material where other substances are used. It is found, by analysis, to contain about 45 parts of silex, 16 of alumine, 20 of oxide of iron, 9 of lime, and from 2½ to 4 parts of pure soda; three of these substances being very powerful fluxes.

Some other minerals have been proposed, on account of the soda which they contain, as well qualified for making glass: such, for instance, is *klingstein*, which contains nearly one twelfth part of its weight of that alkali; but as the other fluxing materials present in basaltic earth are wanting in those other minerals, they prove far less fusible.

Whenever basaltic earth is largely employed in the composition of glass, it usually proves of a dark olive green color, varying sometimes to a very deep yellow; and it does not appear at all probable that this color could in any material degree be corrected. The glass produced is specifically lighter than any common green bottle glass; and at the same time is considerably harder and tougher, so as to bear, without injury, blows which would infallibly break ordinary glass. The quantity of alkali which it contains is small—much smaller, in fact, than is required to bring glass of every other description to a workable state. For this reason basaltic glass is peculiarly well qualified for chemical purposes; as vessels made with it will resist the destructive action of corrosive liquids.

In addition to the experiments already detailed as having

been made by him with basaltic earth, M. Alliot made trial of various other combinations for the production of bottle glass. He succeeded with the two following:—

The first was a mixture in equal parts of ashes and a volcanic granite. This fused perfectly, and produced a very fine dark and lustrous glass, exceedingly well qualified for the composition of bottles. The second was composed of 1 part ordinary soda, 12 parts ashes, and 6 parts common sand. The glass thus formed was of a yellowish black color, interspersed with veins of bluish white, which were opaque.

When the duty shall be removed, and the manufacturer finds himself without restriction in regard to the materials which he may employ, we may expect to witness some considerable improvements in this branch of the glass-maker's art.

CHAP. VI.

OF THE MANUFACTURE OF PLATE GLASS.

Different Descriptions of Plate Glass.—Blown Plates limited in Size.—Cast Plate Works at Ravenhead.—Difficulties of the Process.—Materials.—Various Compositions.—Borax.—Mixing Materials.—Fritting.—Furnaces and Crucibles at St. Gobain.—Pots.—Cuvettes.—Regulation of Firing.—Casting Tables.—Arrangement of Foundery at Ravenhead.—Annealing Ovens.—Process of Casting Plates.—Annealing.—Squaring.—Grinding.—Economical Improvement.—Smoothing.—Emery Powder.—Comparative Value of Large and Small Plates.—Polishing.—Silvering.—Preparation of Amalgam.—Mode of its Application.—Blowing Plate Glass.—Punching.—Partial Cutting.—Transfer to Pontil.—Completion of Cutting.—Opening.—Sizes of Plates.—Effect of Sun's Rays in Discoloring Plate Glass.

Two descriptions of plate glass are made: one by blowing and opening, in the manner of broad glass, as already described; the other by casting the melted materials upon a plane metallic surface, somewhat in the manner pursued for making sheet lead.

Plates of glass which are blown are necessarily limited in their size, although some of considerable dimensions are produced in this way. When cast, the extent of the plates may be much greater; and, indeed, is limited only by the very heavy expense attending the erection of machinery, and the prosecution of the manufacture in its various parts. Different manufactories have been established at various times in this kingdom for the production of plate glass by blowing, but these, one after another, have mostly been discontinued. The last establishment of this kind in London existed a very few years since in East Smithfield; but being a private establishment, and the proprietors finding it impossible to continue a successful compe-

tition with the powerful corporate body alluded to in the first chapter of this treatise, the works have been discontinued; and the only place in England where plate glass of any great magnitude is now manufactured, is on the premises of the British Plate Glass Company in Ravenhead, in Lancashire, where plates are *cast* which equal, in every respect, the produce of the French manufactory at St. Gobain. The office of this corporation is at the foot of Blackfriars Bridge, in London; and here plates of glass of the most perfect quality, and of all dimensions up to the prodigious length of 160 inches, may at all times be procured.

Great reluctance has always been evinced by the proprietors of plate glass works to permit their examination by visitors. Persons are, indeed, occasionally admitted to view the mysteries: but, either by their habits and rank in life, such individuals are unqualified or unlikely to describe what they witness; or the relaxation is made in their favor under a seal of confidence, which renders it impossible that they should impart the information they have acquired. The late Mr. Parkes appears to have been fortunate in this respect; and having obtained permission to visit the works at Ravenhead, was not restrained from publishing a short, but interesting, account of the processes which he witnessed. From this source the following description is drawn, as far, at least, as relates to the buildings and arrangements particularly used at Ravenhead.

More care in the choice of materials, and greater nicety in conducting the processes, are required for the preparation of plate glass than are needed in any other branch of the manufacture. The materials employed are sand, soda, and lime, to which are added manganese and oxide of cobalt as decoloring substances. The sand must be of the finest and whitest kind: the grains should be sharp, and of a moderate size; if very small, they are likely to clot together, and consequently will not mix intimately with the alkali; and if the grains are large, they are on this account longer in being fused. The sand must be passed through a wire sieve of the proper closeness into water, and should be well agitated to separate all dirt and impurities. The alkali used is always soda: this is preferred to potash: as glass made with the former substance is thinner, and flows better while hot, and yet is equally durable when cold. The quality of flowing freely is of the very first importance in casting large plates, which, to be perfect, require to be without streak or bubble. Another advantage attending the use of soda is this;—that the neutral salts of which it is the base, such as muriate and sulphate of soda, and which, in this instance, constitute the glass gall, are dissipated more readily by

the heat of the furnace, than are the salts of which potash is the base. The soda must be used in a state of considerable purity; and is generally either that which is separated from the ashes of barilla, and other soda plants, by lixiviation, or is produced by the decomposition of common salt.

Lime acts in promoting the fusibility of the silex and alkali, fulfilling thus the same office as is performed by litharge in the manufacture of flint glass. From one fifteenth to one twenty-fourth part of the whole materials is the largest proportion that can properly be used of lime; any greater quantity would impair both the color and solidity of the glass.

Manganese would have the effect of giving a slight tinge of red; but when mixed in a proper proportion with the blue of the cobalt, and both together are met by the natural slight yellow of the other materials, each neutralizes the other, so that scarcely any definable tint remains.

In addition to these ingredients, a considerable quantity of fragments of glass, or, as it is called, *cullet*, is used in combination with the fresh materials. Of these fragments there is always an abundant supply in the glass-house, produced from what is spilt in casting, and from the ends and edges that are cut off in shaping the plates. This broken glass, or *cullet*, is previously made friable, by throwing it, while hot, into cold water.

It is considered that the addition of one pound of pure soda is sufficient for four pounds of sand. But it is not enough, in the preparation of glass for casting, to apply the alkali only in the proportion necessary to produce good glass; much more than this must be used, in order to procure the requisite degree of fluidity.

The composition given by Loysel as being used in the great works at St. Gobain is this:—

White sand,	100 parts
Carbonate of lime,	12
Soda,	45 to 48
Fragments of glass of like quality,	100
Oxide of manganese,	0¼

Parkes recommends the following proportions, as qualified to produce plates of glass of the best description:—

Lynn sand, previously well washed and dried,	720 parts
Alkaline salt, containing 40 per cent. of soda,	450
Lime, slaked and sifted,	80
Nitre,	25
Cullet, or broken plate glass,	425
	1700

These quantities are required to produce one pot of *metal*, which will yield 1200 pounds of good plate glass.

Another author states the following proportions as being found to produce very fine glass:—

Fine white sand, ...	300 pounds
Soda, ...	200
Lime, ...	30
Oxide of manganese, ...	32 ounces
Oxide of cobalt, ...	3
Fragments of glass, ...	300 pounds

The well-known property of borax, as a powerful flux, has occasioned the suggestion that, by its means, glass made with potash might be caused to flow in fusion as freely as that wherein soda is employed. It has been asserted that small quantities of borax have always been used in the works at St. Gobain; but the secrecy observed in regard to all the operations carried on in that establishment renders it impossible to say what degree of truth there is in the assertion.

Great care is required in mixing the materials; much more, indeed, than is called for in regard to other kinds of glass. The sand, lime, soda, and manganese, being properly intermingled, are fritted in small furnaces, wherein the temperature is gradually raised to a full red, or even to a white, heat, at which point it is maintained, and the materials are carefully stirred until vapor is no longer given off, and no further change is undergone by the materials. This process of fritting lasts about six hours; and when it is nearly completed, the remaining part of the ingredients, consisting of the cobalt and broken glass, are added. The latter, having already been perfectly vitrified, does not, consequently, require any lengthened exposure to the fire.

The furnaces at St. Gobain, in which the perfect fusion and vitrification are accomplished, are eighteen feet long and fifteen wide. They contain two kinds of crucibles. The larger ones, wherein the glass is melted, are called *pots*, and are formed like inverted truncated cones; the other crucibles, which are smaller, are called *cuvettes:* these last are kept empty in the furnaces, exposed to the full degree of its heat, that when the glass is ready for casting, and is transferred to them, they may not injuriously lower its temperature. The comparative size of these cuvettes varies according to the dimensions of the plates which it is intended to cast: when these are very large, the cuvette will contain one third of the charge of the pot; but in other cases its capacity is not greater than a fourth, a fifth, or a sixth part, of the contents of the crucible.

The method used for regulating the supply of fuel to the fur-

nace in the great works of St. Gobain, is at once so rude and so absurd, that one would hesitate to believe in the correctness of the narration, if it did not rest upon good authority. It is said that two persons are employed, who, being disencumbered of all superfluous clothing, incessantly run round the furnace with a speed "equal to seven leagues in six hours." These men on their circuit take up each two small billets of wood, cut to a certain size, and heaped together; these they deposit as they run, first one and then the other, in the openings of the furnace, which by such means is fed at regularly recurring intervals of time. Having continued this intellectual employment, without ceasing, during six hours, the men then surrender their "seven league boots" to others, whose heels and hands are similarly employed during an equal period of time; after which they are in turn relieved by the first set of couriers.

From the time of filling the pots, it requires nearly forty hours' exposure to strong heat, ere the materials are properly vitrified and in a state fit for casting. The processes of filling the pots, and of removing the glass gall, and the various appearances that ensue in the refining, are precisely similar to what has already been described in a former chapter.

When the glass is thoroughly refined, the cuvette—which must be perfectly clean, and, as already mentioned, of a temperature equal with that of the glass—is filled in the following manner: A copper ladle, ten to twelve inches in diameter, fixed to an iron handle seven feet long, is plunged into the glass pot, and brought up filled with metal glass, which is transferred to the cuvette; the ladle, during this transference, is supported upon a strong iron rest, placed under its bottom, and held by two other workmen. This precaution is necessary to prevent the bending and giving way of the red-hot copper under the weight of fluid glass which it contains. When by successive ladings the cuvette is filled, it is suffered to remain during some hours in the furnace, that the air-bubbles formed by this disturbance may have time to rise and disperse; an effect which is ascertained to have ensued by the inspection of samples withdrawn from time to time for the purpose.

Another essential part of the apparatus consists in flat tables whereon the plates of glass are cast. These tables have perfectly smooth and level metallic surfaces, of suitable dimensions and solidity, supported by masonry. At St. Gobain, and formerly also at Ravenhead, these tables were made of copper; the reason assigned for preferring this metal being, that it does not discolor the hot melted glass, while the use of iron was thought to be accompanied by this disadvantage. These copper tables were very costly, both from the nature of their material, and the labor bestowed in grinding and polishing their surfaces;

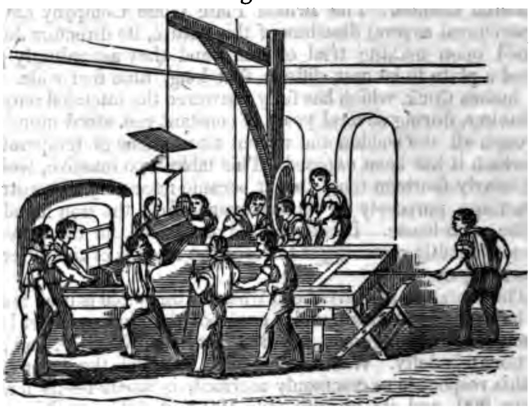
and as the sudden access of heat that accompanied the pouring over them of such a torrent of melted glass occasioned the metal frequently to crack, the tables were by such an accident rendered useless. The British Plate Glass Company having experienced several disasters of this nature, its directors determined upon making trial of iron; and they accordingly procured a plate to be cast, fifteen feet long, nine feet wide, and six inches thick, which has fully answered the intended purpose —having, during several years of constant use, stood uninjured through all the sudden and violent alternations of temperature to which it has been exposed. This table is so massive, weighing nearly fourteen tons, that it became necessary to construct a carriage purposely for its conveyance from the iron foundery to the glass-house. It is supported on casters, for the convenience of readily removing it towards the mouths of the different annealing ovens.

The foundery at Ravenhead wherein this table is used is said to be the largest room under one roof that has ever yet been erected in this kingdom; it is 339 feet long, 155 wide, and proportionately lofty. Westminster Hall, to which the superiority in this respect is so commonly ascribed, is smaller—its length being 300, and its breadth only 100 feet. The melting furnaces, which are ranged down the centre, occupy about one third of the whole area of this apartment. The annealing ovens are placed in two rows, one on each side of the foundery, and occupy the greatest proportion of the side walls. Each of these ovens is sixteen feet wide and forty feet deep. Their floors being level with the surface of the casting table, the plates of glass may be deposited in them immediately after they are cast, with little difficulty and without delay.

When the melted glass in the cuvette is found to be in the exact state that experience has pointed out as being most favorable for its flowing readily and equably, this vessel is withdrawn from the furnace by means of a crane, and is placed upon a low carriage, in order to its removal to the casting table, which, as it is previously placed contiguous to the annealing oven that is to be filled, may therefore be at a considerable distance from the melting furnace. Measures are then taken for cleaning the exterior of the crucible, and for carefully removing with a broad copper sabre any scum that may have formed upon the surface of the glass, as the mixture of any of these foreign matters would infallibly spoil the beauty of the plate. These done, the cuvette is wound up to a sufficient height by a crane; and then, by means of another simple piece of mechanism, is swung over the upper end of the casting table; and being thrown into an inclined position, a torrent of melted glass is

suddenly poured out on the surface of the table, which must previously have been heated, and wiped perfectly clean.

Fig. 12.



The glass is prevented from running off the sides of the table by ribs of metal, one of which is placed along the whole length of each side, their depth being the exact measure which it is desired to give to the thickness of the glass. A similar rib, attached to a cross piece, is temporarily held, during the casting, at the lower end of the table. When the whole contents of the crucible have been delivered, a large hollow copper cylinder, which has been made perfectly true and smooth in a turning-lathe, and which extends entirely across the table, resting on the side ribs, is set in motion; and the glass, during its progress, is spread out into a sheet of uniform breadth and thickness. Its length depends upon the quantity of melted glass contained in the cuvette: should this be more than is needed for the formation of a plate having the full dimensions of the table, the metal rib is removed from its lower part, and the surplus glass is received in a vessel of water placed under the extreme end for the purpose.

Mr. Parkes, in speaking of this operation, remarks—"The spectacle of such a vast body of melted glass poured at once from an immense crucible, on a metallic table of great magnitude, is truly grand; and the variety of colors which the plate exhibits immediately after the roller has passed over it, renders this an operation far more splendid and interesting than can possibly be described."

At least twenty workmen are busily employed during this process of casting. From the time that the cuvette is removed from the furnace, to the completion of the casting by the hardening of the glass, the apartment must be kept as free as possible from disturbance; even the opening and shutting of a door might, by setting the air in motion, disturb the surface of the glass, and thus impair the value of the plate. So soon as it is completely set, the plate is carefully inspected; and should any flaws or bubbles appear upon any part of its surface, it is immediately divided by cutting through them.

When the plate of glass thus formed has been sufficiently fixed by cooling, it is slipped from the table gradually and carefully into one of the annealing ovens, where it remains in a horizontal position; its treatment differing in this respect from that pursued with crown and broad glass, which stand on edge during the annealing process. As each oven in this manner becomes filled, it is closed up by an iron door, the crevices of which are carefully stopped with mortar or clay, to prevent any access of external air to the oven; and thus to provide as far as possible for the gradual cooling of the plates, the necessity for which has already been sufficiently explained. When the glass has remained during about fifteen days in these ovens, they are opened, and the contents withdrawn.

The plates have then to undergo all the operations of squaring, grinding, polishing, and silvering, in order to fit them for sale.

The first process—that of squaring and smoothing the edges—is performed by passing a rough diamond along the surface of the glass, guided by a square rule; the diamond cuts to a certain depth into the substance, when, by gently striking the glass with a small hammer underneath the part which is cut, the piece comes away; and the roughnesses of the edge thus left are removed by pincers. The plate is then taken to the grinding apartment.

The next step is to embed each of the plates upon a table or frame adjusted horizontally, and made of either freestone or wood, cementing the glass securely thereto by plaster of Paris. One plate being then reversed and suspended over another, the material employed in grinding their surfaces is introduced between the two, and they are made to rub steadily and evenly upon each other by means of machinery set in motion by a steam-engine. It was formerly usual to employ river sand and water, for the purpose of abrading the surfaces; a circumstance which entailed considerable waste and loss upon the manufacturers. The glass which was ground off, and which usually amounts to one half the weight of the plates as they are cast,

being thus mixed with a material which contained a portion of iron, was sold at a low rate for making bottle glass, or for scouring pewter. Mr. Parkes has calculated that the loss of glass by this means to one establishment—that which was carried on in East Smithfield—amounted to two tons weekly; and that the expenditure of sand in the same period was at least sixteen to twenty tons.

A method has, however, been devised for saving the whole of this glass, so as to render it available for the manufacture of the better descriptions. This plan consists in substituting, for the river sand before mentioned, ground flints, which contain no portion of iron. A further great advantage attending this method is, that one ton of ground flints is equally effective with five tons of sand, and that the operation is completed in a shorter time than formerly.

When one side of each plate has been sufficiently ground, it is loosened from the frame, and turned over, so as to present the other surface to be ground in the same manner. Some degree of pressure is employed, by loading the upper plate with weights as the grinding of each side approaches to completion. The process thus described used formerly to last during three entire days, but this time is now much abridged. The greatest attention is required, in order to finish with the surfaces perfectly level and parallel, for which end a rule and plumb line are employed.

By means of this grinding, the plates will have been made level, and all inequalities in the surface will have been removed; but they are too rough to receive a polish: to fit them for this, they must again be ground with emery powder of increasing degrees of fineness. The preparation and sorting of this powder are effected in the following simple and ingenious manner:—

A considerable quantity of emery is put into a vessel containing water, and is stirred about violently until the whole is mechanically mixed with the water. Emery is absolutely insoluble by such means; and if the mixture were left at rest during a sufficient time, the whole would subside in layers; the coarsest and heaviest particles sinking first, and so on successively, until the very finest particles would range themselves as the upper stratum. Previously to this, however, and while these finest grains are still suspended in the water, it is poured off into a separate vessel, and the emery is there allowed to settle. A fresh supply of water is poured into the first vessel, the contents of which are again violently agitated, and allowed partially to subside as before. A shorter interval is allowed for this than in the first case; and then the liquor is poured off into

a third vessel, by which means emery of the second degree of fineness is separated. This operation is repeated, in order to obtain powders having four different degrees of fineness: the deposits are then separately dried upon a stove to a consistence proper for making them up into small balls, in which form they are delivered to the workman.

In this further rubbing together, or, as it is called, *smoothing* of the glass plates, it must be understood that the coarsest emery is first used, and so on, substituting powders having increasing degrees of fineness as the work proceeds.

This operation completed, the glass is perfectly even; and although the surfaces appear opaque or deadened, they are so smooth that no scratchiness is at all perceptible. The plates are now again subjected to a rigid examination; and should any flaws or defects be perceptible in them, which had before escaped detection, they are cut up with a diamond into smaller plates, so that the blemishes are left at their edges; regard being had to economy in dividing the glass, so as to produce the smallest possible number of pieces. Attention to this circumstance is of the greatest importance to the profitable working of the establishment, since the value of smaller plates bears no comparison with that of glasses having more considerable dimensions. This may be seen at once in referring to the following table, which has been calculated upon some of the published prices of the British Plate Glass Company.

Dimensions.	Surface in Square Inches.	Price. £.	s.	d.	Price per Sq. Inch. d.
60 inches by 30 inches.	1,800	10	10	1	1·400
60 - - - 40 - -	2,400	16	3	5	1·617
60 - - - 50 - -	3,000	22	10	5	1·800
70 - - - 50 - -	3,500	28	7	8	1·946
80 - - - 50 - -	4,000	34	14	10	2·085
100 - - - 50 - -	5,000	48	9	8	1·327
100 - - - 60 - -	6,000	63	15	1	2·550
100 - - - 70 - -	7,000	80	8	2	2·757
100 - - - 80 - -	8,000	98	4	10	2·947
132 - - - 84 - -	11,088	200	8	0	4·337
160 - - - 80 - -	12,800	246	15	4	4·705

The largest of the plates here mentioned is capable by reduction of being converted into $7\frac{1}{9}$ plates having the dimensions of the smallest in the Table; whereas the price of the former is $23\frac{1}{2}$ times greater than that of each of the small plates, and

more than $3\frac{1}{4}$ times the aggregate value of those into which it would be divided.

The reason for this progressional rate in the prices is sufficiently obvious. Could such a degree of perfection be attained in the different processes of manufacture, that a certainty existed of producing plates of every requisite dimension, there would no longer be any pretence for thus enhancing the prices of the larger pieces; and plates might be sold indiscriminately at so much per superficial foot in the manner usual with linen or woollen fabrics, making perhaps some allowance for the greater expensiveness of machinery required for large than for small operations. But such a degree of certainty is so far from accompanying the labors of the glass-founder, that it is but very rarely he is enabled to finish and produce for sale any plates of extra dimensions; while it most frequently happens that the presence of numerous flaws and bubbles compels the division and subdivision of the glass into portions bearing, for the very reason of their abundance, only a small relative value.

It is represented as being an interesting sight to witness the grinding and smoothing of a great number of plates of large dimensions, which by means of machinery are thus made to move with great velocity, and in all directions.

The next process is that of *polishing*. For this purpose a substance is used, known in commerce and the arts as *colcothar* or *crocus martis*. This is the brown red oxide of iron, which remains in the retorts after the distillation of the acid from sulphate of iron.

The instrument used in polishing is a piece of wood covered with many folds of woollen cloth, each fold having between it some carded wool, so that the whole forms a tolerably hard but elastic cushion; and this is furnished with a handle for the convenience of the workman.

The plate is embedded in plaster upon the table in the manner already described, and the polishing instrument being wetted by means of a brush, and covered with colcothar, the workman commences his operation by rubbing the cushion backward and forward over the surface of the plate; not, indeed, attempting to polish the entire surface at the same time, but operating upon separate portions, beginning at each corner, and proceeding regularly towards the centre, so as to leave no part unvisited by its due degree of attention and labor.

Considerable dexterity and practical skill are needed, not only to produce a high polish upon the plate, but also to give this in an uniform degree over its whole surface; and the finishing touches require, therefore, to be given with great care and judgment.

When one side is polished, the plate is turned on the table, as it has before been in grinding and smoothing; but as the white plaster would appear through the glass and hinder the workman from forming an accurate judgment upon his progress in this second operation, the previously polished side is provided with a coating of red colcothar. When the workman is satisfied with the result of his labor upon this second surface, the plate is taken from the table, and being cleaned, is laid, each side in its turn, upon a dark blue or black cloth, which, as it admits only a moderate light, shows by inspection any parts which may be less elaborately polished than the rest: these must be retouched by a small polishing cushion, in the same manner as before.

It would be a tedious operation, if every small fragment of glass, such pieces, for instance, as are used in swing frames on toilet-tables, must be polished separately. The edges of several of these pieces are therefore brought together for the purpose; but as all these are not of one uniform thickness, it is necessary to remedy this inconvenience; and, in order to bring their surfaces to a perfect level, they are arranged, with the side to be polished downwards, on a large smooth level plate; plaster of Paris is then poured upon their upper surfaces, which are thus embedded together, and on being turned over, the whole number of pieces is found to be so level, that the polishing may be performed as easily and as effectually as it could be with one entire plate.

When the polishing of the plates has been satisfactorily completed, they are washed with water, and are either removed to the ware-room for sale, or, in case of their being intended for mirrors, to the silvering apartment.

The last process used in a plate-glass manufactory is that which is called *silvering*. This, in common with the greater part of the operation connected with this branch of the art, is simple, but requires practice and dexterous management for its proper performance. The application to the posterior surface of mirrors of some substance that will accurately reflect the rays of light falling upon them, is absolutely necessary to render them useful. The substance which has been found to answer this purpose best is mercury; which, as it cannot be applied alone in its fluid state, is, by a partial amalgamation, previously made to adhere to the surface, and afterwards to incorporate itself with the substance of a very thin leaf of tinfoil.

The operation is thus conducted:—A perfectly flat and smooth slab of thick wood, or of stone, somewhat larger than any plate which it may be required to silver, must be inclosed within a wooden frame open at the top, and having a ledge a

few inches deep round three of its sides. The bottom of this frame is provided with a channel to collect the surplus mercury, and to convey it to a vessel placed underneath. The slab is fixed on a pivot, so that one end may be raised and the other depressed at pleasure.

When it is used, the slab must first be adjusted horizontally, and covered with gray paper stretched tightly over it. A sheet of very thin tinfoil, a little larger than the plate to be silvered, is then laid smooth upon the paper, and as much mercury is poured steadily upon it as will remain upon its flat surface. That end of the slab which is unprovided with a ledge is then covered with parchment, and the plate of glass is carefully slidden into the frame, resting the while upon the parchment.

The art of properly effecting this deposit of the glass upon the foil consists in holding it, during its sliding, in such a position that it will dip into the mercury, carrying a portion of the metal before it, but without once touching the tin in its passage. By this means any dust or oxide which may rest upon the mercury will be removed, and no air-bubbles will remain between the glass and the foil; while, if the tin were touched, however slightly, it would certainly be torn.

When the entire surface of the glass plate has thus passed, it is allowed gently to drop on the tinfoil, and to squeeze out the superfluous mercury from between, and which is collected in the channel already mentioned. The plate being then covered with a thick flannel, is loaded at regular intervals of space with considerable weights, and the end of the slab is a little raised, which assists the escape of the superabundant mercury. The whole remains in this situation during the entire day, the slope of the slab being gradually increased to facilitate the dropping of the mercury. At the end of this time, the plate is cautiously taken from the frame, carefully avoiding to touch the under side, then covered uniformly with a soft amalgam of tin and mercury. The plate is then placed in a wooden frame, and left during several days until the amalgam is found to be so far hardened as to adhere with a great degree of firmness to the glass: in this state not even a slight scratch would suffice for its removal. The plate is then in a finished state, and fit for being framed.

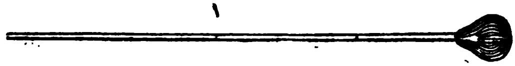
The amalgam does not, however, acquire its greatest degree of hardness until some time has elapsed; and globules of Mercury will occasionally drop from mirrors for some time even after they have been framed. Portions of the amalgam are at times detached while in this state, by violent concussions of the air, such as a thunder storm, or the firing of artillery. No patching can ever be applied in such a case that will be suffi-

ciently perfect to escape detection; but a white seam will invariably be perceptible at the points of junction.

Although the processes followed in *blowing* plate glass are, in most respects, similar to those used in fashioning broad glass, some differencc is yet observed; which, indeed, is occasioned as much through the increased bulk and weight of the mass under operation, as on account of any real difference in the composition of the fabrics; only a very short account of the process can therefore be required.

The first instrument used is a hollow rod, agreeing in every particular, except its size, with that used for forming flint and crown glass. This rod is full six feet in length, and two inches in diameter; made smaller at the end to which the breath is applied, and widened at the extremity upon which the glass is gathered. It is necessary to take up a considerable weight of glass upon this tube; and some management is required in order to effect this. When the workman has gathered all that will adhere by turning the end continually round in the pot, he then withdraws it from the furnace; and holding it over a bucket of water, sprinkles the glass on the end of the tube, turning it constantly round in his hand. When cooled in this manner, the glass adheres firmly to the tube, and is rendered by that means capable of sustaining a greater weight than it would otherwise support. The tube is then dipped again into the pot, and the same process is repeated.

Fig. 13.

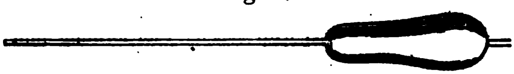


After the third dipping it will have gathered a mass of glass in the shape of a pear, ten inches in diameter, and about twelve inches long. This must again be cooled with sprinkling as before; and while the workman is at the same time blowing into the tube, so as to give a hollow form to the glass, and to reduce it to the requisite thickness, the rod must be swung to and fro with an alternating motion, in order to lengthen the shape of the material; and this proceeding being several times repeated, the glass assumes the form of a cylinder, the lower end of which is hemispherical.

Fig. 14.

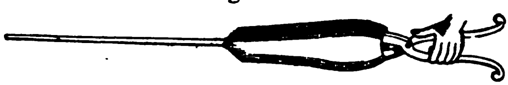
The assistant is then placed three feet and a half from the ground, upon a stool, whereon are fixed two upright pieces of wood, with a cross piece of the same material, for the purpose of supporting the tube with the glass. These are held by the assistant in an oblique position, the end with the glass inclining downwards, that the workman may be able, with an iron punching instrument and a mallet, to drive a hole through the centre of the hemispherical end of the cylinder.

Fig. 15.



The glass now is subjected to examination; and if found sufficiently free from imperfections, is held at the aperture of the furnace during seven or eight minutes to heat it again thoroughly. While thus held, the rod is supported in its horizontal position by a small iron trestle placed before the orifice of the furnace conveniently for that purpose. The glass being thus sufficiently softened by heat, the assistant is again mounted upon the stool; and resting the tube upon the wooden cross-piece, twirls it round, while the workman insinuates a pair of large broad shears which are pointed at the end, into the hole

Fig. 16.

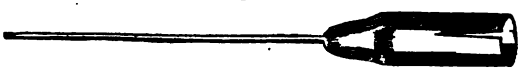


previously punched. This is gradually enlarged, until the glass, through its whole length, and except at the part where it is attached to the tube, has a cylindrical form.

Fig. 17.

The tube is then again rested on the trestle, and the glass is reheated at the furnace, when the shears are used to cut the cylinder through half its length, beginning at the open end, and proceeding towards the point where it is attached to the tube.

Fig. 18.

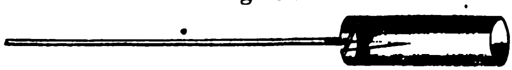


The next proceeding is to take a pontil, an instrument already described as being a solid rod of iron of smaller diameter than the tube, from which last the glass is now to be transferred to the pontil. This differs from the instrument used for the like purpose in making flint glass, by having an iron cross-piece, twelve inches in length, placed across its extreme end, and forming with it the letter T. The pontil being thoroughly heated at the end, a quantity of melted glass is gathered from the pot upon the cross-piece, which being presented to the diameter of the cylinder, the two cohere speedily and firmly together: the hollow tube is then disconnected from the glass in the manner already described.

Fig. 19.

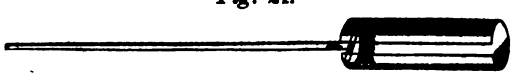
The pontil with the cylinder is now rested on the trestle, and presented to the furnace, that the end which has hitherto been attached to the tube may in turn be heated and subjected to the same processes as have just been effected with the other end: the extremity is opened by introducing the shears so as to complete the cylinder (*fig.* 20.); and then after a fresh

Fig. 20.



heating the workman cuts through the remaining half of the length of the cylinder in a line with and joining to the cut already mentioned, so that the cylinder is divided on one of its sides through its entire length.

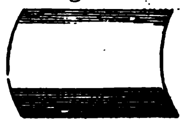
Fig. 21.



The glass is then placed with the cut side upwards upon an iron shovel; it is separated from the pontil, and immediately removed to the hottest part of the annealing oven, where it gradually becomes again heated to redness. Advantage is then taken of the softened state of the cylinder to open it, by the help of an appropriate iron instrument, lifting up and turning back the cut edges of the glass, until the whole is flattened upon the hearth of the annealing oven. A small iron rake is then employed to push the plate along the floor to the end of

the oven; and when this has been filled through a succession of operations such as are here described, the door is stopped

Fig. 22.



and cemented. All further processes are in every respect the same as are followed with plates that have been cast.

The great size and weight of the glass render these operations exceedingly laborious, so that a man and his assistant can hardly do more than make one plate in an hour, nor can they continue their labor longer than six hours, resting during an equal space before they resume their toil.

Plates which are blown cannot properly be made above forty-five, or at most fifty, inches in length, and with a proportionate breadth. They have sometimes been made larger, but are then too thin to admit of their properly bearing the processes of grinding and polishing, and are besides liable to warp, which of course destroys their value when employed as mirrors.

It was long since observed, that by exposing plate glass to the solar rays, it is made to acquire a violet or purple tinge, and this so rapidly, that the alteration is clearly discernible at the end of one or two years. Some plates, originally colorless, which had thus become tinged, having been brought under the notice of Mr. Faraday, he was induced to experiment upon the subject. For this purpose, he procured three different pieces of plate glass, which were tinged so slightly as to appear altogether colorless, unless when viewed through their edges. Each of these pieces was broken into two portions, one of which was wrapped in paper, and set aside in a dark place; while the portion from which it had been separated was exposed to the air and the light of the sun. This exposure was commenced in the month of January; and in the following September a comparative examination was made. The pieces from which the light had been excluded exhibited no sign of change, while those which had been exposed had, in this short space of eight months, acquired so considerable a degree of color as would, under other circumstances, have created a doubt regarding their original identity.

CHAPTER VII.

ON THE COMPOSITION OF ARTIFICIAL GEMS.

Great interest formerly attached to this subject.—Different Compositions for Artificial Gems.—Mode of Preparation.—Rock Crystal formerly employed.—Not superior to Sand.—Diamond Pastes.—Selection of various Pastes for Imitating different Gems.—Reasons for such selection.

A VERY considerable portion of every treatise on glass-making, which was in existence a century ago, and which comprises nearly the whole of what has ever been published on the subject, was devoted to the art of composing factitious gems. A great deal of mystery would seem to have been affected upon this subject on the part of the manufacturers, each one of whom was, or pretended to be, possessed of some secret *recipe*, which he thought superior to all others for the composition of these ornaments.

A corresponding anxiety to acquire a knowledge of these mysteries being evinced on the part of the public, the authors above alluded to, so far acquiesced in this feeling as to load their writings with one receipt after another, in almost endless succession, and in following which the artist was assured, that he might successfully rival nature in the production of these much-admired objects.

The greater part of the compositions thus recommended, if indeed they were ever used, has long since passed into neglect; and it will not be necessary, in the present day, to insert more than a very few directions on the subject, which are given upon the authority of M. Fontanieu, as being well qualified, with the addition of various coloring matters, for counterfeiting precious stones.

No. 1. is composed of 20 parts of litharge, 12 of silex, 4 of nitre, 4 of borax, and 2 parts of white arsenic. These ingredients should be fritted together in a crucible, and afterwards melted, in which state the whole must be poured suddenly into cold water. Any portion of lead which may have been revived in the metallic state will then be apparent and must be separated. The glass may then be remelted for use.

No. 2. For this composition, mix together 20 parts of ceruse, 8 of silex in powder, 4 of carbonate of potash, and 2 of borax. When these are perfectly melted, the whole should be poured into water, and then remelted in a clean crucible, in the same manner as No. 1.

No. 3. consists of 16 parts of minium, 8 of rock crystal in powder, 4 of nitre, and 4 of carbonate of potash. These ingre-

dients must be melted and remelted in the manner already described as necessary with the preceding mixtures.

No. 4 differs essentially from the three foregoing combinations in being without any portion of lead. It is made with 24 parts of borax, 8 parts of rock crystal, and 8 of carbonate of potash. The rock crystal, previous to its use for this purpose, must be reduced to a state of great purity, by fusing it with an excess of alkali and then precipitating it by an excess of acid, in the form of an impalpable powder.

No. 5. The processes necessary for the production of this species of glass are much more complex than the preceding. In the first place, 3 parts of alkali are to be fritted with 1 part of rock crystal, which mixture must then be dissolved in water and saturated with dilute nitric acid. The silex which is precipitated by this means must then be edulcorated and dried, when it will appear in the form of a very fine impalpable powder. Two parts of this must be melted in a crucible with 3 parts, by weight, of the best ceruse, and the glass which results must be poured into water. Break this down and remelt it with one twelfth of its weight of borax, and pour it again into water. If this last product is once more melted with one twelfth of its weight of nitre, the result will be a very fine hard glass, having an extremely beautiful lustre.

The length of time required for fusing hard glasses or *pastes* is at the least twenty-four hours. The process herein directed, of pouring the melted glass into water, and then remelting, is found to be of considerable use in thoroughly and intimately mixing the ingredients together.

Of the foregoing compositions, No. 1. will be found extremely fusible, on account of its considerable proportion of fluxing materials. It calls for the employment of the very best description of crucibles, in order to withstand, for the requisite time, the corroding effects of the mixture. If any kind of glass into the composition of which lead has not entered, is applied to and melted on the interior surface of the crucible, so as to line it with a perfect glaze previous to use, the evil just mentioned will be materially remedied.

In order to make a perfect glass, which at the same time shall be sufficiently workable, 2 parts of silex require from 3 to 4 parts, by weight, of oxide of lead; but a somewhat smaller quantity of the latter may be used, if the deficiency is made up by the addition of some other fluxing material: the glass in this case will prove both hard and brilliant; and, when properly set, will exhibit a much nearer imitation of the diamond than most other vitreous compositions.

It was formerly imagined by artists who wrought these arti-

ficial gems, that if the glass employed by them had for its basis rock crystal, rather than sand, flint, or any other mineral of the like character, the result was a much harder glass than ordinary. This idea is, however, wholly without foundation; for when the crystal has once been fused through the admixture of any kind of flux, the hardness of the mineral will be irrecoverably lost, as this quality depends altogether upon its natural aggregation, which, in such case, is necessarily destroyed.

Rock crystal is, perhaps, somewhat purer than most other siliceous substances, some of which contain minute traces of iron, and which may possibly impair the beauty of some colors which are imparted to glass. The same means as are used to render flint friable, are employed for that purpose with rock crystal: this should on no account be ground in metallic vessels.

Some artists have succeeded, to a certain extent, in producing a very fine, hard, brilliant, and colorless glass paste, in imitation of the diamond, and have even given to this a very considerable play of light, or, as it is technically termed, *water;* but it has not been found practicable to compound any vitreous substance which could for a moment deceive the eye of any person accustomed to witness the superior brilliancy of real gems. The best of these mock diamonds require, indeed, the aid of artifice in the mode of their setting, to render them in any great degree ornamental. M. Fontanieu recommends his glass, No. I, described in this Chapter, as being better qualified than any other for making artificial diamonds. To bring this glass to such a degree of brilliancy and clearness as will prove at all satisfactory, it must be retained in a state of perfect fusion for a considerable space of time.

Loysel recommends, for the same purpose, the employment of a different composition, the result of which will be a glass, having the same specific gravity as the white oriental diamond, and for this reason better imitating that resplendent substance in its refractive and dispersive powers. His recipe is as follows:—

White sand purified by being washed first in muriatic acid, and afterwards in pure water, until all traces of the acid are removed	100 parts.
Red oxide of lead (minium)	150
Calcined potash	30 to 35
Calcined borax	10
Oxide of arsenic	1

This composition is easily fusible at a moderate heat; but like that proposed by Fontanieu, requires to be kept in a melted

state for two or three days, to perfect the refining, and to cause the dissipation of the superabundant alkali.

The same author has furnished the following receipts for the formation of pastes, qualified, upon the addition of appropriate coloring materials, for the imitation of various gems. The remarks already made as to the length of time required for the due preparation of the diamond paste equally apply to these compositions:—

White sand, purified in the manner pointed out in the preceding receipt, ...	100 parts.
Red oxide of lead	200
Calcined potash, and nitre, of each	20 to 25.

The specific gravity of this glass, water being 1, will be 3.9 to 4.

White sand, prepared in the manner before mentioned, ...	100 parts.
Red oxide of lead, ...	300
Calcined potash, ...	5 to 10
Calcined borax, ...	200 to 300

The specific gravity of this compound will vary from 3·3 to 4.

White sand, prepared as above, ...	100 parts.
Red oxide of lead, ...	250
Calcined potash, ...	15 to 20
Calcined borax, ...	25 to 30.

This will have a greater specific gravity varying from 4 to 4.5.

In making his selection between one or other of these pastes, the artist should be guided by their various specific gravities, choosing preferably that glass which is nearest in this respect to the particular gem which he is desirous of imitating; and this, not with the view of providing himself with an additional means of deception, but because, the refractive and dispersive powers of different transparent bodies being determined by their comparative weights, the resemblance will, by such a selection, be rendered more perfect to the eye. To one simple test, that of their hardness, recourse can be had so easily, that every one may, with very little previous instruction, ascertain for himself the genuineness of any gem that is offered to his notice, without any apprehension of being deceived.

CHAP. VIII.

ON THE MANUFACTURE OF GLASS FROM CALCINED BONES.

Preparation of Bones.—Their Vitrification.—Process known to Becher.—Concealed by him.—Curious Suggestion as to its Employment.—This Glass highly electric when newly made.

Glass may be made from calcined bones by digesting them during two or three days with half their weight of sulphuric acid, evaporating to dryness, and washing the residue in many different waters, until all the soluble matter is exhausted. The production of this effect is known by the water having no longer a yellow tinge.

The different waters thus used must then be brought together and evaporated to afford a solid extract. To separate the sulphate of lime contained in this, the extract must be dissolved in the least possible quantity of water, and filtered: the salt will then remain on the filter. This extract may be mixed with powdered charcoal, and distilled for the production of phosphorus; but if, instead of this, it be placed in a large crucible, and the fire is urged, it will at first swell considerably, but ere long will again settle, and at that instant the glass is made. This is white, and of a milky color.

These directions are taken from the System of Chemistry of M. Chaptal; who tells us that before his time Becher was perfectly well acquainted with the use to which bones could thus be applied, but that he concealed the process, on account of the abuse which, according to his apprehensions, might be made of it, and to which he plainly enough alludes in the words—"Homo vitrum est, et in vitrum redigi potest; sicut et omnia animalia." This author was, nevertheless, led to express his regret that the Scythians, who drank from disgusting skulls, were not acquainted with the art of converting them into so cleanly a substance as glass;—and he also showed the possibility of forming a gallery of family effigies, moulded from glass, the produce of the identical bones of the originals, in which the likenesses might be preserved as truly as they now are by the limner. M. Chaptal adds, that a skeleton of nineteen pounds' weight may be made to yield five pounds of this phosphoric glass.

Newly made glass of this description will emit very strong electric sparks, which will fly to the hand at the distance of two inches: but this property ceases after one or two days, however carefully the glass may be preserved from contact with the atmosphere. The substance is in fact phosphoric acid which has

been deprived of its water, and which if not carefully preserved from the atmosphere it will again imbibe, becoming deliquescent. It has an acid taste, and is soluble in water.

CHAP. IX.

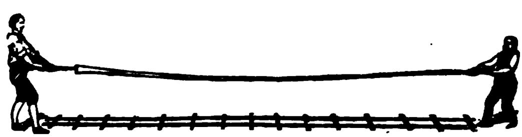
ON THE USE MADE OF THE BLOWPIPE, AND ON VARIOUS SMALL MANUFACTURES OF GLASS.

Thermometer Tubes.—Mode of giving to them an Elliptical Bore.—Blowpipe and Apparatus described.—Materials used.—Method of Working.—Sealing Tubes.—Bending and Joining Tubes.—Bulbs.—Spun Glass.—Watch Glasses.—Lunette Glasses.—Glass Beads.—Manufactory at Murano.—Striped Tubes.—Mode of forming Beads.—Sorting them.—Numerous Kinds of Beads.—Mock Pearls.—Manner of their Invention and formation.—Dial Plates.—How formed.—Lettering and Figuring.

A considerable number of articles are made of glass with the aid of a lamp and blowpipe. The principal of these articles, such as thermometers and barometers, are formed from tubes which are made at the glass-houses, of different bores and substances, by drawing out quickly, and while soft with heat, a thick and short tube into one that is thin and long.

The method of performing this process is, to gather the necessary weight of glass upon the rod; and this glass having been elongated and hollowed by the workman's breath in the usual manner, a punt is attached to the end of the cylinder opposite to the rod. The workman then holding the rod and his assistant the punt, each proceeds in a direction opposite to that taken by the other, by which means the tube is elongated in the necessary degree; and being then made to rest upon billets of wood placed horizontally and parallel to each other at equal distances on the ground, it speedily cools, and may in that state be readily cut into convenient lengths.

Fig. 23.



Whatever may be the original form of this tube and of its perforation, it is found that the same form will be relatively continued throughout the entire length to which it is drawn out. If its perforation be at first cylindrical, it will so continue,

whatever degree of length and minuteness it may be made to assume; and an equal sameness will be found to accompany the prolongation, if any other form be originally given to the orifice.

A method has been suggested by Mr. Wilson, of Glasgow, to render the mercury in a thermometer tube easily observable, without incurring the inconveniencies which attend a large bore. This method is founded on the property above mentioned, and which is indeed common to all ductile substances.* Mr. Wilson proposes to form the tubes with an elliptical perforation, which when drawn out will form a mere slit, the flat side of which is to be turned towards the observer. It does not appear, however, that these tubes have come into any extensive use.

This elliptical bore is caused by flattening, in the necessary degree, and before it is drawn out, the short thick tube already described; restoring then its external cylindric form by coating it over with a further portion of melted glass, and rolling it on the iron slab, mentioned in page 137, in our description of the processes pursued in blowing flint glass.

The apparatus usually employed by those who undertake this branch of glass-working is extremely simple. The table is substantially made, and has fixed at its bottom a small double-blast bellows, worked with a foot-board, that the artist may himself govern its action, and at the same time have both his hands at liberty for the other operations which he has to conduct. A pipe, proceeding from the bellows, conducts the blast of air to the lamp, which is usually nothing but a bundle of coarse cotton thread, placed in a common tin vessel of a horse-shoe shape, the flame being fed with lumps of tallow heaped up and intermixed with the cotton. A small chimney is hung over the lamp, and at a short distance from the flame, to carry off the smoke, which otherwise would be inconvenient to the workman. The blast pipe is so placed and directed that it throws off the jet of flame from the lamp in a direction contrary to that occupied by the workman, so that all annoyance from this source is equally avoided.

Two or three very simple iron tools, such as files, forceps, scissors, &c., make up the rest of the glass-worker's apparatus; while his materials are mostly confined to an assortment of tubes having various bores, and composed of different thicknesses of glass. When employed in making toys or ornaments of glass, tubes of various colors are provided by the workman: these are easily procurable at any glass-house, a good stock of

* For a beautiful scientific application of this principle, see Lardner's Mechanics, Cab. Cyc. p. 9. art. (12.)

all kinds of tubing being generally kept by the makers. The flame, when most strongly urged by the blowpipe, is about four inches long, having its end of a blunt round form; its color, in the part nearest to the wick, is of clear light blue, and beyond this of a pale yellow, the blue portion having by far the greatest heating power.

In proceeding to work, care must be taken to remove all moisture from the tubes, both within and on the outside; they must be heated gradually, to prevent their cracking; and the greater the thickness of the glass, the more necessity there is for caution on this head. Glass is so imperfect a conductor of heat, that where utensils made with it of any considerable thickness have fire applied to them, it is difficult to prevent an unequal degree of expansion, which induces that corresponding inequality of pressure among the different parts under which some will inevitably give way and fly asunder. It is for this reason that glasses intended for use in chemical laboratories can hardly be made too thin, or with too great attention to the equality of their substance, so that heat may be quickly and uniformly transmitted through the mass.

Glass tubes should be first heated by being held in the flame of the lamp, without employing the blast of air; they should next be brought to the yellow outer edge of the flame when urged by the blowpipe; and, lastly, the fusion must be completed through bringing the glass by slow degrees within the hottest part of the flame.

The power of a blowpipe, such as is usually employed for these purposes, is sufficient for bringing to a white heat a solid lump of glass large enough to form a bulb which will contain three fluid ounces; a size much larger than can be required for purposes to which the lamp is usually applied.

It may be well to describe briefly one or two operations, such as are usually effected by means of the lamp and blowpipe; from which will be made apparent the great facility wherewith this seemingly refractory substance can be moulded, through the agency of heat, according to the will of the workman.

If it be wished to seal a tube hermetically, that is, to close it effectually at the end by causing the intimate union of its particles, it will suffice that the part be held during a short time in the flame, turning the tube round with the fingers so as to occasion an equal action upon every part: by this means the end will presently be so far softened, or partially fused, that the particles will fall in and run together; thus effectually closing the orifice, and producing the appearance of a small button at the extremity. This operation may be hastened, if, when the glass is rendered soft by heat, and before any fusion has ensued,

the parts are brought into contact towards their common centre by means of a stout iron needle. In some cases, and particularly when the tube is of any considerable substance, the button thus formed on the end would be inconveniently large, and might besides either fly in cooling, or be accidentally broken. This can be remedied by lessening, in the following manner, the quantity of glass whereof it is composed.

The end being softened in the flame of the lamp, and another piece of tube of the same size having been equally acted upon, the two ends are to be brought together, and may, by a very little management, be firmly united. If then the tube which is to be sealed is softened a little higher up than the point of union, and the two tubes are pulled gently in opposite directions until they separate, that which is heated will be drawn out with a diminished substance, and may be easily sealed in the part that is required, the joined ends and a portion of the sealed tube remaining attached to the waste piece.

In making some kinds of thermometers, and for various purposes connected with experimental chemistry, it is often required to bend tubes of glass: when these are of small bore, and their substance is tolerably thick, it is only requisite to hold the tube in the weaker part of the flame, in order to soften it through about one or two inches of its length, when it may be slowly and gently brought to the shape required.

Something more than this is needed if the tube be wide and its substance thin. In order to preserve in such case the particular form of the bore, and to prevent its being much straightened, or perhaps closed at the bend, as it most probably would be if no precaution were taken against it, one end of the tube should be hermetically sealed; and during the time the workman employs himself in bending it at the required part, he should also blow steadily but very gently into the open end. The pressure of his breath employed in this manner, will keep the softened part of the tube distended in the proper degree, so that it cannot collapse during the bending, and the perforation will be maintained in its original form. The closed end of the tube may be readily cut off by first scratching with a file and then breaking it suddenly; an operation which, with a very little care, may be performed without risk of dividing the tube in any other part of its length.

Two tubes may be joined together with tolerable accuracy by heating their ends in the flame, and then bringing them into contact; turning them round in opposite directions with a screwing motion, in order to complete their junction. If it be desired to remove the thickened ring of glass which will thus be produced, one end of the tube must then be previously seal-

ed; and when the union has been fully completed in the way described, and while the glass is yet soft, the workman must blow into the open end, and gently pull the tube at the point of junction, until the ring disappears, and the whole tube becomes equally cylindrical.

In forming hollow bulbs at the end of tubes, such, for instance, as are required in making thermometers, the following process must be used:—The end whereat the bulb is to be formed must be sealed; and in order to collect at this extremity the needful quantity of glass, it must be pressed while yet quite hot upon some hard surface, by which means that part is somewhat shortened and consolidated into a lump. This must then be held in the most intense flame of the blowpipe until it is quite white hot; being then removed, and the breath applied moderately and steadily to the open end, and keeping the tube in the meanwhile with the heated end hanging downwards, the lump will be enlarged into a spherical bulb, the diameter, and consequently the substance, of which can be regulated according to the pleasure of the workman.

It has been already mentioned that glass may be spun into very long and minute threads, with great velocity, when the mass from which it is drawn has been previously heated. For this operation the use of the blowpipe is required, and the manner of its performance is very simple.

The lump of glass being sufficiently softened by the flame, another piece of glass is applied to it, when the two, cohering together, and being then drawn apart, are seen to be connected by minute filaments. A fine thread being thus obtained, its end is applied to a wheel or reel, and the heat of the glass being maintained, while the wheel is turned with considerable velocity, a thread may be drawn continuously out as long as the workman pleases, or until the store of glass is wholly expended.

The thread thus made is extremely flexible and delicately fine. Its firmness depends in a great measure upon the heat whereat the glass is maintained, and upon the velocity wherewith the wheel is turned: the greater these are, the firmer will be the thread.

Glass is only treated in this manner in order to afford a pleasing exemplification of some of its properties, or for purposes of ornament. When it is desired to produce colored threads, the material employed should be embued with a very deep tint, as, when drawn out in such minute filaments, it would otherwise appear nearly colorless.

The preparation of watch-glasses involves a series of simple but interesting processes. Only a part of these is performed at

the glass-house; the remainder being the objects of a separate, and, when viewed with reference to its extent, by no means unimportant branch of trade and manufacture.

All that is effected by the glass-blower is the production of regular hollow spheres, each being eight inches in diameter, and weighing twelve ounces.

It is a circumstance, perhaps, not the least deserving of notice, in detailing the operations of the glass-house, that the men employed to gather glass from the pots for this and similar purposes, upon the end of the hollow rods, attain through constant practice so much proficiency as to bring away with the greatest accuracy exactly the quantity that is needed for the formation of the required object. To such a degree is this correctness carried, that, on weighing many dozens of spheres such as have just been described, not one has been found that varies half an ounce from the proper weight.

The blowing of these hollow globes is performed with great celerity. Owing to the circumstance that the glass of which they are composed is exceedingly thin, so that their cooling, although rapid, is also effected with considerable regularity through their substance; and because in the further progress towards their ultimate form they are again to be softened by heat, these globes are delivered to the watch-glass maker as soon as they are blown, and without passing through the annealing oven.

The first operation performed by the last-mentioned artist is to divide each sphere into the largest possible number of sections of the requisite size; it being manifest that any errors committed at this stage of the proceeding would, by wasting his material, place the manufacturer at a disadvantage.

In proceeding to effect this division, the workman seats himself; and taking the globe in his lap, with a piece of heated wire or tobacco-pipe, (which last is perhaps chosen preferably, because it longer retains a sufficient degree of heat,) he traces a line upon the globe, and quickly thereafter wetting the line thus traced, the glass will crack and divide along the line with the most admirable precision. The sections thus obtained will necessarily have many angular irregularities: these are dexterously clipped away by means of scissors.

The segments into which the individual pieces have now been cut, will be wanting in the requisite degree of convexity. Before this can be imparted to them, they must have their brittleness removed, and be considerably softened by heat. When this has been effected, taking an appropriate instrument in each hand, and using them much in the same manner as the dairy-maid employs her wooden spoons in raising a pat of butter,

the workman presses the edges of the glass regularly in towards the centre, which is by this means made to rise in a corresponding proportion. The edges are then ground evenly off, and the watch-glass is ready for sale.

Lunette glasses are differently made. These are not segments of spheres, but have their edges abruptly raised, and their interior areas or faces flattened. In forming these lunettes, a much smaller quantity of glass is gathered from the pot than is required in blowing globes for ordinary watch-glasses. A hollow pear-shaped figure is then blown, having the larger end, which is farthest from the extremity of the rod, of the size required for a watch-glass, and the requisite flatness is occasioned by pressing this end, while soft, upon any smooth level surface.

These glasses are necessarily much higher in price than those more commonly used for watches; both because they are made to contain a greater weight of glass, and because, only one form being cut from each hollow pear-shaped figure, the labor expended in the manufacture is proportionally greater.

A very considerable manufacture of glass for the formation of beads is carried on at a place called Murano, situated near the city of Venice. There is nothing peculiar in the composition of the glass made use of for this purpose, nor in the methods employed for its preparation; and although the manufacturers affect great secrecy as to the coloring substances which they mix with the glass, it is not likely that they possess any real advantage over others in this respect, or that they have made any useful discovery of materials different from those commonly employed in coloring glass.

When upon inspection the colored glass is found to be in a fit state for working, the necessary quantity is gathered in the usual manner upon the rod, and is blown into a hollow form. A second workman then provides himself with an appropriate instrument, with which he takes hold of the glass at the end which is farthest from the extremity of the rod, and the two men running thereupon expeditiously in exactly opposite directions, the glass is drawn out into a pipe or tube, in the manner of those used for constructing thermometers, the thickness of which depends upon the distance by which the men separate themselves. Whatever this thickness may be, the perforation of the tube is preserved, and bears the same proportion relatively to the substance of the glass as was originally given to it by the blower. In these particulars the workmen of course govern themselves according to the size and description of the beads which are to be made. The glass-house at Murano is

provided with a kind of gallery 150 feet in length, and which much resembles a rope-walk, wherein the tubes are drawn out in the manner here described.

Tubes striped with different colors are made by gathering from two or more pots lumps of different colored glass, which are united by twisting them together before they are drawn out to the requisite length.

As soon as they are sufficiently cool for the purpose, the tubes are divided into equal lengths, sorted according to their colors and sizes, packed in chests, and then dispatched to the city of Venice, within which the actual manufacture of the beads is conducted.

When they arrive at the bead manufactory, the tubes are again very carefully inspected, and sorted according to their different diameters, preparatory to their being cut into pieces sufficiently small for making beads.

For performing this latter operation, a sharp iron instrument is provided, shaped like a chisel, and securely fixed in a block of wood. Placing the glass tube upon the edge of this tool at the part to be separated; the workman then, with another sharp instrument in his hand, cuts, or rather chips, the pipe into pieces of the requisite size; the skill of the man being shown by the uniformity of size preserved between the different fragments.

The minute pieces thus obtained are in the next process thrown into a bowl containing a mixture of sand and wood-ashes, in which they are continually stirred about until the perforations in the pieces are all filled by the sand and ashes. This provision is indispensable, in order to prevent the sides from falling together when softened by heat in the next operation.

A metallic vessel with a long handle is then provided, wherein the pieces of glass are placed, together with a further quantity of wood-ashes and sand; and the whole being subjected to heat over a charcoal fire, are continually stirred with a hatchet-shaped spatula. By this simple means the beads acquire their globular form.

When this has been imparted, and the beads are again cool, they are agitated in sieves, in order to separate the sand and ashes; this done, thev are transferred to other sieves of different degrees of fineness, in order to divide the beads according to their various sizes. Those of each size are then, after being strung by children upon separate threads, made up into bundles, and packed in casks for exportation.

In this manner, not fewer than sixty different kinds of glass beads are prepared in vast quantities. The principal trade in

these is carried on with Spain and the coast of Africa; but some portions find their way to nearly all parts of the world.

Another and a more costly description of glass beads, made in imitation of pearls, has long been produced in France. Although the name of the inventor of these ornaments has been faithfully preserved, the period of their invention is not precisely known. Reaumur, on whose assertions the greatest reliance may generally be placed, states this to have occurred in 1656. An anecdote related by Beckmann* of a cheat successfully played off upon a lady by a French nobleman, leads to the conclusion that thirty years later than the period here mentioned, these mock pearls were far from being generally introduced or even known.

The manner of their invention was this:—M. Jaquin having observed that upon washing a small fish, the *Cyprinus alburnus*, or bleak, the water contained numerous fine particles, having the color of silver, and a pearly lustre, he suffered the water to stand for some time, and, collecting the sediment, covered with it some beads made of plaster of Paris, the favorable appearance of which induced him to manufacture more of the same kind for sale. These were at first eagerly adopted; but the ladies soon finding that when they were exposed to heat, the lustrous coating transferred itself from the beads to their skin, they were as quickly discarded.

The next attempt of M. Jaquin was more successful. He procured some glass tubes of a quality easily fusible, and, by means of a blowpipe, converted these into numerous hollow globules. He then proceeded to line the interior surface of these with the powdered fish-scales, which he called essence of pearl, or *essence d'Orient.* This was rendered adhesive by being mixed with a solution of isinglass, when it was introduced in a heated state inside the globules, and spread over the whole interior surface, by shaking the beads which, for that purpose, were placed in a bowl upon the table. These hollow beads being blown exceedingly thin, in order to produce a better effect, were consequently very tender. To remedy this evil, as soon as the pearly varnish was sufficiently dry, they were filled with white wax, and being then bored through with a needle, were threaded for sale.

An expert workman can blow from five to six thousand small glass globules in a day; but, as some attention is called for in regard to the shape and appearance of these beads, the produce of a man's daily labor will not much exceed one fourth of that quantity. The closer to counterfeit nature in their manufacture,

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* Hist. of Inventions, vol. ii. art. *Artificial Pearls.*

these beads are sometimes purposely made with blemishes, and of somewhat irregular forms. Some are made pear-shaped; others are elongated like olives; and others again are flattened on one side, in imitation of natural pearls, which are set in a manner to show only one side.

The fish whose scales are put to this use are about four inches in length. They are found in great abundance in some rivers; and, being exceedingly voracious, suffer themselves to be taken without difficulty. The scales furnished by 250 of these fish will not weigh more than an ounce, and this will not yield more than a fourth of that quantity of the pearly powder applicable to the preparation of beads; so that 16,000 fish are required in order to obtain only one pound of the *essence of pearl.*

Up to a recent period, the heirs of Jaquin, the first inventor, carried on a considerable manufactory of these mock pearls in Paris. The fish are tolerably abundant in the river Seine; but their scales are conveyed from distant parts in much larger quantities than can be procured on the spot, for which purpose they are preserved in volatile alkali.

The dial-plates of clocks and watches are made of opaque white glass, which has acquired the name of enamel. The peculiarly delicate appearance of these, as well as their opaqueness, result from the presence of oxide of tin.

These plates, which are not of greater diameter than twelve inches, are made in one piece; but any which are required to be larger than this, must be formed in separate segments, and afterwards joined together.

In the preparation of dial-plates, the first process is that of hammering a thin plate of copper of the requisite size upon a slightly concave anvil constructed of hard wood; for which operation a convex hammer is employed, and in this manner the proper state of convexity is imparted to the plate, without impairing in any degree the smoothness of its surface.

The centre hole for the hour and minute hands, as well as that whereby the key must be introduced for the purpose of winding up the clock or watch, together with other smaller holes, for the screws by which the dial is to be attached to the works, are all made by passing tools of appropriate forms and sizes through the copper, from the concave side, in such a manner that the metal displaced in the act may form ridges round the holes on the convex side, and be instrumental in retaining the enamel to the requisite thickness upon the surface, when in its state of fusion. For this same purpose, the outside edge of the plate is hammered up all round, so as to form a ridge of the requisite depth; and provision must be made for this rim

in the size originally given to the copper. The metallic plate thus formed is thoroughly cleansed by being immersed in a weak dilution of nitric acid, after which it is dipped in pure water, and rubbed smartly over with a brush formed of brass wires.

The white enamel is then broken in a hardened steel mortar, until it is reduced to fragments about the size of fine sand; and the whole should be brought as nearly as possible to the same state as regards the size of the particles. The pounded glass is then washed in very clear water, and the heavier parts having subsided, the remaining milky-looking liquid is poured off and left to settle in a separate vessel. This operation is several times repeated; so that the powder may be divided into separate portions, having different degrees of fineness.

The enamel being thus sorted and well washed, the separate portions are placed in glass vessels, and nitric acid is poured over, so as completely to cover the powders. The acid must be left on the enamel during the space of twelve hours, the whole being occasionally stirred with a glass spatula, in order to dissolve away any metallic particles which may have been abraded from the steel mortar, and which would greatly impair the whiteness of the enamel when subsequently applied on the face of the plate. The acid is then poured off, and the enamel washed in successive waters, until it no longer contains any acidity; after which, it is again covered with pure water, and in this state it must remain until used, that its perfect whiteness and purity may be preserved.

It is necessary to operate upon both sides of the plate, lest the heat of the enamel, when in a state of fusion on the convex side, should alter the curvature of the copper, and deform its shape.

The enamel, when prepared in the manner described, is first applied to the concave or under face; in which process the artist spreads over it with a spatula, as thin and as evenly as possible, a portion of the finer settlings. A tool which had previously been inserted in the centre hole is then withdrawn, and its place supplied with a rag of clean linen, which absorbs all the superfluous water from the enamel, bringing it to such a state of consistency, that this, which is called the counter-enamelling, will adhere sufficiently to the copper when the position of the plate shall be reversed. In then proceeding to operate upon the convex surface, the plate must be turned over, a tool being again placed in the centre hole, and a layer of the coarser part of the pounded glass thereafter applied with every possible care as to the evenness of its distribution. It is particularly requisite to cover well the edges of the dial-plate, as

well as those of the different holes, lest the heat should afterwards act too powerfully upon the metal. To draw off the superfluous moisture from this layer of enamel, a fine linen cloth is applied round the entire edge, which, in this altered position of the dial, is now its lowest part, and has in that respect taken the place of the centre hole in the counter-enamelling process first mentioned. In order that the particles may arrange themselves properly and closely together, the tool still remaining in the centre hole is then subjected to two or three slight concussions, and much of the beautiful appearance of the finished dial-plate depends upon the neatness with which this operation is performed. If the enamel is evenly spread and well packed together, no hollows will be left below the surface when it has been melted, and the requisite degree of smoothness will be attained. To dissipate any moisture which may now be retained by the enamel, the plate is dried on a sheet of iron over a chafing-dish.

The dial-plate, thus prepared, is introduced cautiously and by degrees under a muffle placed in a furnace, it being necessary to heat it gradually: in this situation it must remain until it is perceived that the enamel begins to melt; the sheet of iron on which the dial is placed should then be turned gently round, in order that every part may be equally exposed to the heat of the muffle. So soon as the enamel is seen to be perfectly melted over the whole surface, the plate must be withdrawn with as much caution and deliberateness as was used upon its introduction; and, in order to prevent the cracking and scaling off to which the glass would otherwise be liable, the plate must remain for some time cooling very gradually at the mouth of the muffle. The necessity for this delay in the process arises from the same physical law which obliges the manufacturer to have recourse in larger operations to the annealing oven.

When this first firing has been completed, the plate must be cleaned, as before, with a very weak dilution of nitric acid; and a layer of the finer settlings of the enamel is to be spread, in the manner already described, over the convex side. It is not necessary to apply any further coating to the inner or concave surface, unless upon examination any part of the former layer shall appear defective; in which case such part must be made good with a further portion of the same division of the enamel as was used before.

The same precautions that were observed in the first firing for placing the dial-plate within, and for removing it from the muffle, must be repeated now; and must equally be practised when a third layer, which must be of the finest and whitest

portion of the enamel, is subsequently spread over the convex side. When this third layer has in its turn been fused and gradually cooled, the dial-plate is complete, with the exception of the figures or lettering, which must be placed upon the convex side to mark the divisions of the hours and minutes, and which are thus applied:—

A black enamel, which is so composed that it will fuse at a lower degree of heat than the white opaque glass already employed, is to be ground exceedingly fine in an agate mortar with a pestle of the same substance, and in combination with oil of lavender; which, as it would of itself be too thick, must have its consistence reduced by the addition of oil of turpentine. To such an exceeding degree of fineness is it considered necessary to reduce this black enamel for the purpose, that the labor of half a day is usually employed in thus grinding a drachm weight. A further quantity of the mixed essential oils must afterwards be added, that the enamel may be sufficiently thin to flow readily from the pencil.

The dial-plate is then placed upon some level surface, and by means of a pair of compasses, having one of the legs blunt at the end and rounded, so that it will freely turn in the centre hole where it is placed, and the other leg provided with a black-lead pencil, two circular lines are slightly traced at unequal distances from the centre, between which the numerals are to be inserted. The exact position of these is determined by means of a sector furnished with a movable limb; and the different figures being drawn with a camel's hair pencil charged with the prepared black enamel, this is left to become pefectly dry in the air; and its fusion having afterwards been effected in the muffle, the dial-plate is completed, and in a fit state to be placed in the hands of the clockmaker.

CHAP. X.

ON THE FORMATION OF LENSES.

Preparations of the necessary Tools.—Choice of Glass.—Grinding.—Polishing.—Curdled Lenses.—Means used for avoiding this Defect.

In grinding glass for spectacles, or preparing them as lenses for optical instruments, the first thing to be attended to is to determine the proper focal distance of the glass. Taking then a pair of compasses, which, on the supposition that the glass is intended to be convex or concave on both sides, must be opened to the full focal distance; two arches or segments of circles, each extended somewhat beyond the breadth which it is intended to give to the glass, must be described upon a piece of sheet copper, which must then be filed away from the outside of one and from the inside of the other arch. By this means two gauges are formed, the one convex and the other concave, and each perfectly answering to the other.

If it is intended that the glass shall be what the opticians call plano-convex or plano-concave, that is, having one of its sides flat, while the other has received the requisite curvature, the compasses wherewith the arches are described should be opened to only one half the focal distance.

Two circular plates of brass, about one-tenth of an inch in thickness, and each being of a little larger diameter than the intended lenses, are then securely soldered upon a cylindrical piece of lead of an equal diameter with the brass discs, and one inch in thickness; these, which are called tools, are then fixed in the lathe, and turned so as to correspond with the copper gauges, the surface of one being made convex, and of the other concave.

The two brass discs are then to be ground together with emery, or with pounded Turkey-stone, until their surfaces exactly coincide in every point.

If the focal distance is very short, so that the convexity and concavity require to be very considerable, the brass discs should be hammered as nearly as possible to their intended form before they are soldered to the leaden cylinders, and turned; otherwise either the thickness of the brasses would require to be inconveniently increased, or the more considerable portion of their substance, which must in such case be cut away, would occasion the discs to be too thin and yielding.

The glass of which a lens is composed is chosen with reference to the purpose to which it is to be applied, and according to its refractive and dispersive powers: its selection must be

left to the discretion of the optician. Its two surfaces should originally be perfectly parallel. Being cut or clipped into a circular form by means of scissors or pincers, the edge must be smoothed on a common grindstone, and the glass fixed by seating one of its surfaces in softened pitch on the flat end of a solid, cylindrical, wooden handle of smaller diameter than the glass. The centre of the axis of this handle must coincide exactly with the centre of the glass.

If, to suit a short focal distance, the curvature of the lens requires to be great, it will simplify the labor of the artist, if, previously to its being thus fitted to its handle, the glass is reduced upon the grindstone as nearly as possible to the shape of the gauge. Some judgment is, however, necessary in this process, lest the abrasion should be carried too far, even in any one minute point, which would render the glass wholly unserviceable.

The convex form is that which is most commonly given to lenses; and in describing the process for effecting this, the mode of producing concave glasses will equally be understood; the only difference between the two methods being this,—that in the first operation, the concave tool and gauge are brought into use; while for the other, those having a convex form are employed.

The whole being thus prepared, the concave tool is fixed firmly on the working bench; and having some fine emery sprinkled on its surface, the glass is worked upon it with circular and cross strokes alternately; the artist being careful that the centre of the glass shall never pass beyond the edge of the tool.

When by these means the glass has been so far ground that its surface coincides with that of the tool at every point, the emery is to be washed away, and some of the finer kind substituted; and so on through three or four different degrees of fineness, until all the roughnesses and apparent scratches on the glass are worn down, and it has become perfectly smooth to the touch, although dull and opaque to the eye: after this it is sometimes further ground with finely pounded pumice-stone.

At the expiration of every five or six minutes, during this grinding process, the surface of the tool is rubbed for a short time within the concave tool, that its proper curvature may be perfectly preserved. When the operation has been completed, the glass is easily separated from its wooden handle by means of a thin knife, and the pitch is removed by rubbing it with oil. The side which has been ground is, in its turn, fixed upon the wooden handle, and the other side is then ground in the same manner as the first.

Convex glasses are frequently prepared for common purposes,

in another manner. The concave tool is fixed upon the lathe, and the glass being held steadily in the hand, and sprinkled with emery, is applied to the tool during its revolutions. For concave glasses, the convex tool is fitted to the lathe, and the glass is in like manner presented to it; but this method, although easier and more expeditious, is greatly inferior in its result to hand-grinding, and cannot be resorted to when any thing like perfectness in the intended instrument is desired.

The same brass tool which is used for grinding, serves also for polishing lenses; but before it is thus employed, a smooth thick piece of felt must be stretched over and cemented to it, and the outer surface being then covered with washed putty powder, which is a combination of the oxides of tin and lead, the tool is worked upon the lens with the same motions as are employed in grinding it. The consistency of the powder is a point requiring attention; for if it be too moist, it will cause the fibres of the felt to rise up and polish, not only the surface, properly speaking, but likewise the innumerable hollows, which, notwithstanding all appearances to the contrary, are actually left in the surface from the grinding. If the lens be subjected to examination in a microscope, this effect will be rendered fully apparent. The evil consequence resulting from this defect is, that the cavities being polished, admit the rays of light, and disperse, instead of collecting them, as would be the case if the surface were uniform. When this fault exists in a degree so exaggerated as to be visible to the naked eye, the lens is said to be *curdled*.

An excellent method has lately been adopted by an eminent optician in London, whereby this defect is avoided. Bees' wax is hardened to a proper degree by admixture with dry red sulphate of iron, which has previously been carefully washed; and instead of the covering of felt, this compound is melted over the brass tool. When cold, the casing thus formed is sufficiently hardened to be turned to the required curvature, and the tool, when this has been done, is in a fit state for use.

The peculiar advantage of this compound, as a polishing substance, consists in its perfect uniformity; besides which, it has this further recommendation, that if any hard particles should accidentally insinuate themselves between the tool and the lens, and which in other circumstances would scratch the glass, the wax is sufficiently yielding to allow them to bury themselves in its substance, so that all injury of this kind is avoided.

Lenses which have been thus treated, will bear examination with a microscope, their polish appearing uniformly clear and defined.

Convex lenses in their simple state have been used for collecting the heating rays of the sun, or for forming what are called burning-glasses. One of the largest lenses ever applied to this purpose was made of flint glass by Mr. Parker. The diameter of this glass was 3 feet; its focal distance was 45 inches; and the circular spot of light which it cast at the focal point was 1 inch in diameter. Still farther, and as much as possible to condense the rays, Mr. Parker employed a smaller lens, 13 inches in diameter, in conjunction with the larger one, and by means of this the heating rays were concentrated at the focal point to ⅜ of an inch. The effects produced by this arrangement were surprising: 20 grains of pure gold were fused in 4 seconds; the same effect was produced on 10 grains of platina in 3 seconds; and a diamond, whose weight was 10 grains, was found to have lost 4 grains after having been placed within the focus during 30 minutes.

This lens, which cost 700*l*., has since passed into the possession of the emperor of China.

CHAP. XI.

ON THE PRINCIPAL DEFECTS OBSERVABLE IN GLASS.

Striæ—Render Glass unfit for Optical Purposes.—Threads—Render Glass fragile.—Cause of this.—Tears—One of the greatest Defects.—Render Glass useless.—Knots.—Bubbles.—Whence they proceed.—Do not much affect the Quality of Glass.—Objects to be attained for avoiding these Defects.—M. Guinand.—His humble Origin.—Energy of Character.—Examines Telescopes, and constructs others.—Unable to procure Glass of good Quality.—Is incited to examine into the Causes of Inferiority.—His extraordinary Perseverance amidst Accidents and Difficulties.—His ultimate Success.—Accident leading to further Improvement.—Prosecutes his art in Bavaria.—Returns to Switzerland, and further pursues his favorite Object.—Dies.—Frauenhofer.—Rises from Obscurity by his Talents.—His Scientific Acquirements.—Produces Specimens of perfect Glass.—Dies at an early Age.—Respect paid to his Memory.

The principal defects observable in manufactured glass, are *striæ*, *threads*, *tears*, and *knots*. These, when they occur to any extent, all impair its beauty, and some of them injure its actual quality. Although it is not difficult to attain such an amount of proficiency in the manufacture as will preserve the materials from these evils in their extreme degree, yet, altogether to avoid their occurrence, and to obtain glass of a perfect quality, is a task that long, and with only doubtful success, has engaged the thoughts and labors of men devoted to scientific pursuits. The difficulties that attend the attainment of this object are sufficiently proved by the fact that, during ten years, one of the most considerable and most scientific opticians

in London has been disappointed in his efforts to procure a disc of flint glass only five inches in diameter, sufficiently fitted, by the absence of defects, to be employed in the construction of a telescope.

Striæ are undulating appearances, perfectly vitrified, and equally transparent with any other part of the glass: they do not occasion any roughness or inequality in the surface, but result from a want of congruity in the composition of the particles which make up the substance: in other words, the structure is not perfectly homogeneous; and although each different portion may be altogether good in itself, and the whole mass, if made up of any one of these portions, would be equally perfect in itself, yet, the whole acting without any uniformity, the rays of light in passing through them are bent or refracted differently, and the objects beyond appear distorted.

This condition must exist to a considerable extent to be easily discernible by the naked eye, or detrimental to the quality of the glass, when applied to the more ordinary purposes of use or ornament; but glass striated in a scarcely perceptible degree, is yet wholly inapplicable to the construction of optical instruments, where the objects they are intended to present to the eye will be many times magnified; and where, consequently, every defect or distortion that accompanies their transmission through the glass will be equally enlarged. The end proposed in the employment of these philosophical instruments, is the minutely accurate examination of distant or very diminutive objects; and this purpose it is evident must be completely frustrated, by the defect here described.

The name of threads is usually given to fibrous appearances in the body of the glass, which result from the vitrification of clay. Their color is greener than that of the rest of the glass. Threads, if existing in great numbers, render the material extremely fragile; and the same effect is produced, if, although fewer in number, the threads are individually larger. The cause of this increased brittleness is, that the dilation and contraction, at different temperatures, of glass, which results from the fusion of clay, differ from those of glass made with siliceous sand; for which reason, each in turn exerts a hurtful influence upon the other.

Tears are, perhaps, the greatest defect that can be found in glass. They are in fact an exaggeration of the imperfection last described, and usually proceed from the fusion and vitrification of portions of the clay that forms the arch of the furnace, and which are suffered to drop into the pots, and to float in the glass while in its state of fusion. Wherever these tears exist, the material is brittle in a very high degree, so as fre-

quently to crack, without any apparent cause, by the mere effect of the unequal expansion just described, which accident is more likely to occur in proportion as the drops are nearer to the surface. This defect is one of so serious a nature, that it is usual, on discovering its existence, at once to throw aside the glass as useless. In places where, as is frequently the case in England, covered crucibles are employed, this accident is in a great degree avoided.

Three kinds of knots are observable in glass; one of these arises from the aggregation of several imperfectly vitrified grains of sand. Another is owing to some portions of glass gall not having been removed during the refining; and the third kind is produced by any small parts of the crucible or of the furnace which, having been abraded by the rubbing of the tools or other accidental circumstance, have fallen into the glass.

Small bubbles are frequently seen abundantly spread throughout the substance of the glass. These indicate an imperfect degree of refining, and proceed from the disengagement of gas which occurs during the process of vitrification. Their presence announces that the glass has not been sufficiently fluid in the course of its refining to allow of their dispersion. This may happen through one of two causes, either that a sufficient amount of fluxing material has not been used with the sand, or that the fire has not been sufficiently intense for the due liquefaction of the compound. These bubbles are chiefly objectionable on account of their unsightly appearance, and do not really deteriorate the quality of the glass even for optical purposes. In this case each bubble acts as a small convex lens, rapidly turning aside the rays which strike against it, and occasioning a diminution of light in proportion to its area. But when these bubbles are even numerous, the sum of their united areas will amount to only a small proportion of the whole surface of the glass; and the loss of light will be inconsiderable.*

It thus appears that the principal object to be sought after in the manufacture of perfectly homogeneous glass is, to avoid those variations in the composition and specific gravity of its different parts, which occasion the striated appearance described above. To enter minutely, and at length, into a consideration of the means that have been proposed and adopted with a view to remedy this considerable evil, would present little that is amusing to the general reader; while those persons who feel any particular interest in the subject, or whose

* Mr Faraday, Bakerian Lect.; Phil. Trans. 1830, p. 7.

taste for scientific research leads them to admire the detail of well considered and ably conducted plans for the mastery of a difficult operation, may gratify themselves by consulting Mr. Faraday's truly valuable paper already referred to, and which will be found comprised in the Philosophical Transactions for the year 1830.

Some exceedingly favorable specimens of glass for optical purposes have lately been prepared by Mr. Green, the proprietor of the Stangate Glass-house; a gentleman whose personal attention has been unintermittingly given during many years to all the practical operations and details of an extensive establishment. Mr. Green is far from asserting that in what has been accomplished he has arrived at any certainty in the solution of this difficult problem, and feels that at most he has hitherto made only an approach to it; while, however, it is such an approach as justifies the hope, that, through continued thought and exertion, a still greater and more important degree of perfection may be attained.

The circumstances which attended the long-continued and laborious investigations on this subject of another and a very extraordinary man, are, in themselves, so curious and interesting, and seem likely to be followed by such important consequences, to at least one branch of the art, that a treatise on the manufacture of glass might be justly charged with incompleteness, if it did not furnish at least a sketch of those circumstances.

The following account is condensed from a memoir, read at a sitting of the Society of Physics and Natural History of Geneva, on the 19th of February, 1823, as given in the nineteenth volume of the Quarterly Journal of Science, published in London in the year 1825.

The late M. Guinand was born in an inconsiderable village, among the mountains of Neufchâtel in Switzerland. His father was by trade a joiner, and must have been in very indifferent circumstances, as his son was called upon to assist him when only ten years old, and without having acquired more than a very imperfect knowledge of the first rudiments of learning; a deficiency which was never afterwards supplied, as M. Guinand always read with difficulty, and wrote very imperfectly. He must, even at this early period, have been a lad of considerable talent, and of a disposition that urged him to the exertion requisite for raising his condition in society. We find him, when between thirteen and fourteen years old, having quitted the employment of a joiner for that of a cabinet-maker, chiefly engaged in making cases for clocks. At this period he acquired from an acquaintance some knowledge of the art of

casting and working in metals, of which knowledge he afterwards availed himself by adopting, when twenty years of age, the occupation of a watch-case maker, the manufacture of watches forming a very considerable branch of industry in that part of the country.

At the house of a person for whom he then worked, M. J. Droz, the constructor of several automaton figures, which forty years ago made the tour of Europe, young Guinand enjoyed an opportunity of seeing for the first time a very fine reflecting telescope which had been made in England, and which at once appeared to him so curious and interesting an object, that he petitioned for and obtained leave to take it in pieces, the more minutely to examine its construction. The use made of this permission was soon rendered apparent by the production of a similar telescope; and this, which he had constructed with his own hands, on being examined by many competent persons, was pronounced by them to be equal in excellence to that which had served him as a pattern.

Surprised at this success, the gentleman to whose kindness he owed this opportunity questioned the artist as to his acquaintance with the science of optics, and in particular to what treatise he was indebted for his proficiency. The surprise of M. Droz was naturally increased on learning that the instrument had been produced without any knowledge whatever of the theory of optics, and with no more acquaintance with the practice of the art than had been acquired through the examination of the English instrument. M. Droz immediately placed a treatise on the subject in the hands of the young man, which he rather deciphered than read; but the substance of which was imbibed by him so completely, that he was enabled, after witnessing the making of one pair of spectacles, to form and polish lenses, and to make spectacles for himself and others, which were pronounced to be excellent. His principal amusement at this time was found in manufacturing telescopes, which he got up at a cheap rate, forming the tubes of pasteboard.

When the important discovery of achromatic glasses reached Switzerland, Guinand's mind was very strongly excited by it; nd M. Droz having obtained a telescope of the new construcion, again permitted the young man to examine its various parts and structure. The very imperfect state of the arts at that time in Switzerland, and the deficient means of Guinand, prevented his achieving the construction of a similar instrument. He was unable to produce glasses of different refractive power; and it was not until several years after that an acquaintance, making a visit to England, conveyed to him a piece of flint glass, with which, although it was by no means void of

imperfections, being considerably striated, he succeeded in making some tolerably good achromatic glasses. Finding that not only the glass which he had himself worked, but that every other specimen which he examined was thus imperfect, he was incited to a more particular scrutiny into the subject, and bringing into action all the knowledge he had acquired in the art of fusion, he melted in his furnace the fragments of his flint glass. All the satisfaction derived from this experiment was the acquirement of some degree of knowledge as to the composition of flint glass, some particles of lead being revived in the metallic state during the process. Guinand was thirty-five years old at the time when this fresh incitement led to his seeking after such chemical knowledge as might assist him in experiments on vitrification, and his evenings' employment during six or seven years was to melt in his blast furnace a few pounds' weight of glass, carefully noting down every circumstance attending each experiment, that he might be enabled to continue such as afforded any prospect of advantage, and to avoid others which had a contrary tendency.

These small experiments led to no decisive results; and he was upwards of forty years old when, having undertaken a new and more profitable trade, that of making bells for repeating-watches, he was enabled to devote more of his earnings to the prosecution of experiments, which he thenceforth undertook upon a scale more likely by their results to reward his perseverance.

In this pursuit he was still exposed to numerous accidents and difficulties, which would have deterred most persons from continuing the research. His furnace, which he had constructed with his own hands, out of such materials as he could procure, and which was capable of melting at once 200 lbs. weight of glass, proved defective. He was then obliged to procure materials for the purpose from abroad; and having once more completed its erection, and consumed much fuel in heating it, had the mortification to find that it still required alteration. Then his crucibles, which he was equally obliged to form with materials ill-qualified for the object, cracked during the process, and the vitreous matter was lost among the ashes of his furnace. Although during all this time his family arrangements were formed upon a plan of the most rigid economy, he was compelled to employ an interval between each one of his experiments in earning at his regular employment sufficient means for subsistence, and for providing the apparatus, materials, and fuel needful for renewing them.

All this time the pursuit had laid hold so completely of his mind, that he was deprived of his natural rest while considering

upon the causes of his various failures, and endeavoring to reason out the means for their prevention.

Having at length succeeded in obtaining a block of glass weighing about 200 pounds, and having sawn it into two vertical sections, he polished one of the faces, in order, as far as possible, to examine the circumstances produced by the fusion.

To account for the numerous and various defects exhibited by this specimen, M. Guinand formed a theory which he made the groundwork of his future operations. A more intimate knowledge of those defects, and a conviction thus attained of the great difficulties opposed to their removal, instead of damping his ardor in the pursuit, served to infuse new energy into his mind. Nor was he mistaken in his estimate of the obstacles to be surmounted; "so that," as he himself declared, "the sacrifices and exertions which he had previously made were trifling when compared with those which he afterwards underwent for the purpose of removing these various defects, and of rendering his glass homogeneous."

The steps through which he pursued this arduous undertaking, and the methods by which its success was accomplished, it is not possible to detail. All that is publicly known upon the subject is, that he succeeded in discovering a mode of proceeding which gave the almost certainty of producing in the fusion of a pot containing from 200 to 400 pounds of glass, one half at least of its substance entirely homogeneous, and therefore fitted for the construction of perfect optical instruments. With this result, satisfactory as it would have been to most men, Guinand expressed himself by no means contented, and continued his researches, without, however, ever arriving much nearer to perfection in the art.

He was now enabled to make for use discs of glass perfectly homogeneous, with a diameter of twelve inches; a great achievement, when compared with what had been at any time accomplished by others.

On one occasion the artist had succeeded, through much carefulness and exertion, in obtaining a disc eighteen inches in diameter, and of a quality perfectly satisfactory. This was already finished and placed in the annealing oven to cool gradually, when, through some unaccountable accident, the fire caught the roof of his humble dwelling. With some trouble the flames were extinguished; but the water used for this purpose had found its way into the oven, and the precious deposit was destroyed. It is said that the discouragement caused by this accident prevented M. Guinand from afterwards attempting any similarly extensive experiment. He entertained no doubt, however, that, with means for operating on a larger scale than

he could accomplish, lenses of double or even triple the diameter here mentioned might be produced.

For some time after he had thus far succeeded in his object, M. Guinand was accustomed to divide his blocks of glass by that which appeared the only fitting method, sawing them into sections perpendicular to their axis, polishing the sections, and then selecting such parts as were adapted to his purpose, returning the remaining portions to the crucible for future operations. By this means he had frequently the mortification of perceiving that the glass was divided, so as to present a less extended surface of perfect material than the state of the block would, if previously known, have rendered possible; and he was frequently able to procure discs of only small diameter, when, could he have been fully aware of the particular circumstances of the glass throughout its substance, he might, by cutting in another direction, have obtained a more satisfactory result.

This disadvantage was remedied in a way apparently as untoward as it was singular and unexpected. While his men were one day carrying a block of glass on a hand-barrow to a water saw-mill, which he had constructed at the fall of the river Doubs, a short distance from his dwelling, the mass accidently slipped, and, rolling to the bottom of a rocky declivity, was broken into several pieces. Endeavoring to make the best of this seeming misfortune, such fragments of glass were selected for operation as appeared to be fitted by their homogeneity for the purpose; and these were softened in circular moulds, in such a manner that they furnished discs of a very satisfactory quality. Further examination enabled Guinand to perceive that the fracture had in a great measure followed the variations of density in the glass; and, pursuing the idea thus obtained, the artist thenceforth adhered to a method so singularly in the first instance forced upon him.

After this, M. Guinand contrived a mode of cleaving the glass while cooling, so that the fracture accompanied the direction of the more faulty parts; by which course he frequently obtained masses of glass which were absolutely homogeneous, weighing from forty to fifty pounds. These masses, cleft again by means of wedges into pieces of convenient shape, were remelted in moulds which gave them the form of discs; an operation which differs essentially from that used by other glass-makers.

Several years of his life were thus employed by this extraordinary man in making bells for repeating-watches, and constructing achromatic telescopes with glass of his own preparing. The retired spot wherein he resided, offered only very

limited opportunities for acquiring a reputation in the world; yet, by degrees, the superior value of his labors became appreciated, and he was visited by such men of science as travelled into the neighborhood of his dwelling. By one of these, a knowledge of his merits was conveyed to M. Frauenhofer, the chief of a celebrated manufactory for optical instruments, established at Benedictbeurn in Bavaria. This gentleman having in consequence obtained some discs of glass made by Guinand, found their quality so satisfactory, that he repaired in person to Brenets, where the artist resided, and engaged him to settle in Bavaria. This was in 1805, when Guinand was upwards of sixty years of age. He continued at Benedictbeurn during nine years, occupied solely in the manufacture of glass, to the great increase of M. Frauenhofer's reputation.

Being desirous, at the end of this time, to return to his native land, a pension was granted to him by the establishment, on condition that he should no longer employ himself in making glass, nor disclose his process to any person whatever; a condition which did not long agree with the still active energies of his mind. Believing that by new experiments he could raise his discovery to a yet higher degree of improvement, he obtained the consent of M. Frauenhofer to cancel their subsisting agreement; and relinquishing his pension, once again devoted himself with ardor to his favorite pursuit.

M. Guinand lived for several years after this time (1816,) and produced several telescopes of great magnitude, and remarkable for their excellence; it being perhaps not the least extraordinary among the circumstances attending them, that, to use the words of the memoir, whence the foregoing account is drawn, "they have been constructed by an old man upwards of seventy, who himself manufactures the flint and crown glass which he uses in their construction, after having made with his own hands the vitrifying furnace and his crucibles; who, without any mathematical knowledge, devises a graphic method of ascertaining the proportions of the curves that must be given to the lenses, afterwards works and polishes them by means peculiar to himself; and lastly, constructs all the parts of the different mountings, either with joints or on stands, melts and turns the plates, solders the tubes, prepares the wood, and compounds the varnish."

Arrangements had been made by the French government for purchasing his secret, when the artist, verging on his eightieth year, died, after a short illness. That secret did not, however, die with him, but is possessed by his son, who continues to labor in the employment so singularly commenced, and so successfully and energetically followed by his father.

The name of Frauenhofer, which has been introduced in the foregoing narrative, is one intimately connected with inquiries in the art of making perfect glass. It would be wrong to leave the reader under an impression that the merit of this artist was limited to the single act of patronage extended towards Guinand, and which, although indicative of his discernment as a tradesman, would afford no reason for investing him with any part of the extraordinary merit which truly belonged to his character.

Like Guinand, his beginning in life was humble; being indebted solely to the powers of his own mind for the eminence to which he attained. Having occupied the lowest station as an ordinary workman in a great manufacturing establishment, he, by the force of his transcendent talents, and in the course of a few years, raised himself to the chief direction of its business. During the intervals of labor he acquired a competent knowledge of mathematical science; and devoting himself to the perfection of the refracting telescope, proved that he possessed a truly philosophical and scientific mind. Having soon mastered the theoretical difficulties which presented themselves, he still, however, found all his labors unavailing, through the imperfection of the material employed; and set himself to remedy this evil, by a series of admirable experiments.

It might be thought invidious to inquire in what degree his success in these was owing to the previous labors and assistance of Guinand, or how far his discoveries were personal and original. Both produced and left behind them specimens of perfect glass in large pieces; but the public has equally in either case to regret the want of knowledge as to the processes employed for the attainment of an object so desirable.

Frauenhofer died in the year 1826, at an early age; a victim, it is said, to unremitting attention bestowed upon an unhealthy employment. Had his life been continued to the same lengthened period as was allotted to his fellow-laborer, what might not the world have expected from one, who so early had burst the chains of ignorance, and overcome the paralyzing difficulties of birth and adverse fortune; taking his station during life among the genuine philosophers of the age, and falling, admired, and lamented, and eulogized by the most scientific societies of Europe!

The great value of flint glass, from which all perceptible defects are absent, may be imagined from the sketch which has here been given of the efforts made for its production. Very high prices are, in fact, paid for object glasses of a satisfactory quality, which are of any magnitude; while even small fragments of such glass are sought after by opticians with

great avidity. A few years ago the director of one of the London glass-houses having made a pot of flint glass for optical purposes, sold this, in the regular course of his business, to a commission merchant, who transmitted it to his correspondent on the Continent. Some months having elapsed thereafter, during which time its possessor had ascertained the true value of his purchase, the manufacturer was surprised at receiving numerous inquiries on the subject of this lump of glass, on the part of several English opticians. These were anxious to procure portions of a material, the fame of which had reached them from abroad. Upon this, the maker instituted a search, and having succeeded in identifying some fragments, as having formed part of the same melting, was enabled to procure very considerable prices for that upon which he had previously set little or no value, and which had been preserved only through accident.

On a yet more recent occasion, information having reached London that a large and superior object glass was on sale in the metropolis of a neighboring kingdom, one of our most celebrated astronomers hastened across the channel, and while others were chaffering with its possessor about the price, our countryman stept in, and paying at once the full amount demanded, brought off the prize, to the great mortification of his competitors.

CHAP. XII.

ON THE SPECIFIC GRAVITY OF GLASS.

Importance of this Quality.—Experiments of Loysel.—His Reasonings and Formulæ.—Specific weight augmented by Lime.—Mixed Glasses.—Their Specific weight.—Method of Determining this.—Influence of Temperature on the Specific weight of Glass.

The specific gravity of glass is a quality of considerable importance, when the material is required for conversion into the object-glasses of achromatic telescopes, or for the composition of counterfeit gems, although any very minute attention to this point is not considered essential in conducting the commoner processes of the glass-house.

Loysel, to whose justly esteemed work on the art of glass-making allusion has been so frequently made in these pages, went through a series of experiments upon the specific gravities of various vitreous bodies, with the view of giving such instructions for the composition of the nicer qualities of glass,

as should absolve manufacturers from the necessity of making those preliminary trials upon every occasion, which are attended by much inconvenient delay in the prosecution of extensive operations.

Adopting the practical aim of this French author, some of his ingenious formulæ will be here given, together with a statement of the premises whereupon they were founded.

The specific gravity of water being expressed by the number 100, that of sand is 263; while soda deprived of all carbonic acid by fusion in the furnace of a glass-house, is of the specific weight 199, and the same substance, when brought again by cooling to a concrete state, is not heavier than 222. It might, therefore, be supposed that the specific weight of glass, considered as a compound of sand and alkali, would be diminished in proportion as its dose of silica was lessened and that of its alkali was augmented. The contrary of this fact results, however, from the combination of these two substances through the agency of fire.

"Sand," says M. Loysel, "contains, in addition to silica, some other substance, the nature of which has not been investigated, and which is sensibly disengaged from the silica by the alkali, in the form of an elastic fluid, in the act of their combination to form glass.

"We are ignorant of the degree wherein caloric adheres more or less strongly to one or other of these substances; in other words, their capacity for heat is not known; but, in order to avoid errors, it will suffice, that we know the results of several similar combinations. If we ascertain carefully the doses of silica and alkali, which compose glasses formed of these substances at different degrees of heat, together with their various specific gravities, we perceive that the differences between their doses of alkali are obviously proportional to the differences of their weights. Knowing then how far these proportions vary in respect of two descriptions of glass, we have it in our power to compute, with respect to a third composition, either its quantity of alkali from its specific gravity, or, on the other hand, its weight from its dose of alkali."

From actual experiments made on different glasses, the following results have been obtained, the weight of water being expressed by 100:—

Glass, No. 1.	contained	80	parts silica,	20	parts alkali, its specific gravity	236
No. 2	——	54	— silica,	46	— alkali, its specific gravity	254
Difference		26				18

If it be then required to know what proportions of the same materials must be used for the production of another glass,

No. 3., the specific gravity of which will be 242, the solution of the question may be found by the following formulæ :—As the difference between the specific weights of the compounds 1. and 2., which is 18, is to the difference between the weights of 1. and 3., which is 6 : so is the difference between the doses of alkali employed in Nos. 1. and 2., which is 26, to the difference between the doses of Nos. 1. and 3., and which difference is thus found to be 9. Adding then this number to that which represents the alkali of No. 1., we may conclude that the glass of No. 3. must contain 29 parts of alkali and 71 parts of silica. It has been proved by experiment that glass of the specific gravity proposed, 242, is composed by the union of 70 of silica with 30 of alkali.

When a manufacturer has thus two well-established results to serve as general means of comparison, the simple ascertainment of specific gravities will suffice for determining if any variation has taken place in the manufacture, as well as for discovering, and in general remedying, its cause.

If any lime enters into its composition, as is the case with glass of common quality, its weight is rapidly augmented, and it is therefore useful to determine, from time to time, the weight of the glass produced, comparing it with that of some other sample which is known to have been well and carefully made. If it is seen that the weight increases, it may be concluded, either that a larger proportion than usual of lime is present, or that the fire has not been sufficienty urged, and that too large a proportion of alkali has been allowed to remain in combination with the glass.

The rule already stated is said by M. Loysel to apply with equal certainty to the heavy glasses composed of silica and oxide of lead, the differences between the weights of various specimens of flint-glass being also proportional to the differences in their quantities of metallic oxide :—

Glass, No. 1. composed of	27 sand	73	minium, has a specific gravity of	520
No. 2.	—	11	— 89	—	657
Difference			16		137

From these data, the specific gravity of another composition, No. 3.—made up of 20 parts sand and 80 parts minium, may thus be ascertained :—As the difference between the quantities of minium contained in Nos. 1. and 2. is to the difference between the proportional quantities of minium in Nos. 1. and 3. ; so is the difference between the weights of 1. and 2. to the difference between the specific gravities of 1. and 2., and which is thus found to amount to 59 ; which number, the quantity of

oxide being greater in No. 3., must be added to 520, the weight of No. 1., and we thus have 579 as the weight of the proposed composition.

In forming flint glass, it is proper, in addition to the sand and minium above supposed, to employ alkaline substances; and it is desirable that the manufacturer should have it in his power to predict, within a trifling amount, the specific weight of every compound that he may determine to employ. The means to be employed by him for the attainment of this end are founded on the following considerations:—

The manufacture of flint glass requires the employment of a lower degree of heat than is necessary for the formation of other descriptions, which do not contain an equal abundance of fluxing materials for vitrifying the sand. The temperature of the furnace is commonly such, that if glass be made in it composed of silica and alkali in such proportions that the one will saturate the other, it will usually contain about 75 parts of silica, and 25 parts of alkali; and this glass will have a specific gravity of about 24. The same means of heating being employed, 73 parts of minium will be saturated by 27 parts of sand, producing glass the specific weight of which is 52. In practice, it is, however, probable, that 75 parts of minium will combine with 25 of sand, and the result will have the specific gravity of 54.

On the other hand, if two glasses of different character, one of which is composed of silica and alkali, and the other of silica and lead, are melted together, the specific gravity of each being known, the weight of the compound resulting from their union will depart in only a very trifling degree from that which would be given by calculation, according to the usual rules for determining the specific gravities of alloys. The same result will equally ensue, if, instead of thus previously forming two different kinds of glass, the materials of which they should be composed are themselves brought together for the purpose of their original vitrification.

If, then, we consider the sand of the composition as divided into two portions, one of which must necessarily combine with the minium for its vitrification, while the other is required for the saturation of the alkali—the surplus quantity, if any, of the latter constituent being dissipated by heat during the process of vitrification, the calculation necessary for determining the weight of the compound will proceed according to the following example:—

Let it be supposed that the manufacturer wishes to form flint glass by the union of 100 parts of sand, 50 parts of minium, and 40 of potash. These materials might be divided into the

following proportions for producing two very different descriptions of glass:—Thus, the 50 parts of minium, which would be reduced in the process of vitrification to 48 parts, would be completely vitrified by the addition of 16 parts of sand; the absolute weight of glass thus formed would be 64, and its specific weight (that of water being 10) would, as before stated, be 54. The quantity of sand remaining (84 parts) might be combined with the whole of the potash; but as, in the process of vitrification, all the surplus quantity of the alkali would be dissipated, glass would be formed containing 84 parts of sand and 28 of potash, having 112 as its absolute, and 24 as its specific weight. If, then, the whole materials are placed together in the crucible for their original vitrification, we shall have, after the reduction of the minium by 2 parts, and the dissipation by heat of 12 parts of potash, a glass, the absolute weight of which is 176, and whereof we desire to know the specific gravity. For ascertaining this, the specific weights of the two kinds of glass that might be separately formed, must be multiplied into each other, and their sum again multiplied by the absolute weight of both, in order to find a dividend. Proceeding, then, with the absolute weights of the two descriptions of glass which might be formed, and multiplying each separately by the specific weight of the other, adding the two products together, another sum will be obtained, by employing which as a divisor, the quotient will be equal to the specific gravity of the compound.

Thus, in the above example, the specific weights, 54 and 24, of the two descriptions, being multiplied into each other, and their sum multiplied by 176, the absolute weight of both, a product will be obtained of 228,096 for the dividend. Multiplying, then, 64, the absolute weight of one glass, by 24, the specific weight of the other; and again, 112, the absolute weight of the remaining glass, by the remaining specific weight 54, we have two sums, 1536 and 6048, which, added together, and employed as a divisor, gives, as its quotient, a very minute fraction over 30, which is known to be the specific gravity of glass composed of sand, minium, and potash, in the proportions first stated.

With respect to heavy glasses, results are obtained by calculation, which are rather greater than the reality; a circumstance for which it is not difficult to account. The great abundance of oxide of lead used in their composition, attacks the body of the crucible, so as partially to dissolve it; and being thus provided with a somewhat larger proportion of the lighter material, the weight of the compound will be necessarily and proportionally diminished. This difference between the com-

puted and the real weights will, of course, be greater, according as the proportion of minium is augmented; its action upon the crucible being, by such means, rendered more destructive.

Notwithstanding the degree of uncertainty thus occasioned, it must still be useful to know how, by a very simple calculation, to make a near approximation to the truth, and thus, as already said, to avoid the necessity of conducting long and uncertain preliminary experiments.

The specific gravity of glass is influenced by the degree of heat to which it has been exposed during its vitrification; being always least when the temperature has been greatest. The cause of this variation is to be found in the different quantities of alkali that have been dissipated, the silica appearing to depart from the completeness of its aggregation, in proportion as it is deprived of alkali.*

Flint glass is not entitled to any drawback upon its exportation, unless its specific gravity be at least three times that of water. The duty drawn back on the shipment of flint glass is considerably greater than the rate originally paid on other descriptions; and but for the resort which is had to its gravity as a test, those other descriptions might in many cases be substituted, and a considerable profit be thereby fraudulently obtained by the exporter at the expense of the revenue.

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* The rule for ascertaining the mean specific gravity of different bodies should never be relied on until verified by experiment. The condensation of volume which some substances undergo when brought into combination with others, is such as to render all calculations concerning them, under such circumstances, vague and erroneous. From the experiments of M. Loysel it would appear, however, that except in the case which he has noticed, that of employing different degrees of heat, this condensation does not occur with the various compositions of which glass is formed, and recourse may therefore be had to the formula usually employed for ascertaining mean specific gravities, when we desire to determine those of different vitreous combinations. The rule is as follows:

The specific gravity of one body is to that of another, as the weight of the first divided by its volume is to the weight of the second divided by its volume; and the mean specific gravity of the two is found by dividing the sum of the weights by the sum of the volumes.

Let W, w, be the two weights; V, v, the two volumes; P, p, the two specific gravities; and M, the calculated mean specific gravity.

Then, $\mathrm{M} = \dfrac{\mathrm{W}+w}{\mathrm{V}+v}$; and $\mathrm{V}+v = \dfrac{\mathrm{W}}{\mathrm{P}} + \dfrac{w}{p} = \dfrac{\mathrm{W}p+w\mathrm{P}}{\mathrm{P}p}$; hence

$$\frac{\mathrm{W}+w}{\mathrm{V}+v} = \frac{\mathrm{W}+w}{\dfrac{\mathrm{W}p+w\mathrm{P}}{\mathrm{P}p}} = \frac{(\mathrm{W}+w)\,\mathrm{P}p}{\mathrm{P}w+p\mathrm{W}} = \mathrm{M}.$$

CHAP. XIII.

ON THE ART OF COLORING GLASS.

Antiquity of the Art.—Specimens of Roman Mosaic.—Analysis of these by Klaproth.—Metallic Oxides.—Gold Purple.—Its great Coloring Power.—Cassius.—His Precedency in Coloring Glass.—Yellow Colors—From Silver—From Lead—From Tin—From Antimony—Charcoal—From Oxide of Iron.—Green.—Black Glass.—Blue.—Directions found in old Authors.—Imitation of the Garnet—Of the Amethyst—Of the Emerald—Of Sapphire.—Opaque Glasses—Black—White—Opal.—Ancient Pictures formed of Colored Glass—How executed.—Description of Ancient Mosaics.—More recent Prosecution of this Art.—Accidental Coloring of Plate Glass by the Sun.—Ineffectual Attempts to reproduce this Effect.

It appears probable that the art of coloring glass was discovered and prosecuted at a period very little subsequent to that of the manufacture of the article itself. The most ancient authors who have mentioned the existence of the material, have also recorded the fact of its being tinged with various colors, in imitation of gems. Strabo, Seneca, and Pliny, all make mention of this use, as being one to which glass was applied by artists in very early times.

The fact has already been mentioned of colored figures having been found with Egyptian mummies, and which are, therefore, known to have been in existence for upwards of 3000 years. These curious relics of ancient times have also been discovered decorated with colored glass beads; and a mummy thus ornamented is to be seen in the British Museum.

In the reign of Augustus, the Romans began the use of colored glass in the composition of mosaic decorations. Several specimens of this kind have been found at a late period, among the ruins of a villa built by Tiberius in the island of Capri; and some of these specimens having been subjected to analysis by the accurate and ingenious Klaproth, it is known that in that early time recourse was had to the same class of coloring ingredients as is employed by the moderns. Some difference must, indeed, have been observed in their processes, as the ancients were unacquainted with the use of the mineral acids, which are now found to be so convenient in the preparation of metallic oxides.

Klaproth has given the following as the result of his examination of some of the Roman specimens above mentioned:—

One which was a lively copper red, opaque, and very bright where recently fractured, contained, in 200 grains,—

Silex	142
Oxide of lead	28
copper	15
iron	2
Alumine	5
Lime	3
	195

Another, a light verdigris green, also opaque, with a splendent fracture and scoriaceous, contained in a similar quantity,—

Silex	130
Oxide of copper	20
lead	15
iron	7
Lime	13
Alumine	11
	196

It is remarkable that the constituent ingredients of both these specimens should prove to be the same. The difference between them exists only in their relative proportions; and the colors depend upon the different degrees of oxidation of the copper. Sub-oxide of copper,—that is, copper which has combined with itself only half the quantity of oxygen required for the production of the perfect oxide—produces a red enamel; while that which has received its full proportion of oxygen yields a green enamel color.

The specimen of ancient blue glass which was analyzed by Klaproth contained,—

Silex	163 parts.
Oxide of iron	19
copper	1
Alumine	3
Lime	0½
	186½

It appears, therefore, to have been indebted to the oxide of iron for its blue color, as no trace was detected of any other ingredient to which this could be referred. Since the discovery of the certain and commodious method of producing blue enamel by means of cobalt, the art of obtaining this color from iron has been lost.

The causes which influence the employment of metallic oxides for the embellishment of porcelain have been sufficiently detailed in the preceding treatise. The same reasons also oblige the artist to have recourse to the same class of substances for imparting colors to glass. The mode of application of coloring materials to these two branches of manufacture differs, however, in this,—that while, in ornamenting porcelain, they are applied superficially, in the manner of pigments, they enter more intimately into the composition of glass, being transfused through the whole mass, and equally incorporated with its entire substance.

The preparation of metallic oxides as coloring materials is nearly similar in all cases; it will not, therefore, be necessary here to repeat directions, or to give many explanations upon that head.

Gold, in a state of great division and oxidated, has long been celebrated as a means for imparting to glass a most exquisite purple-red color resembling the ruby, and nearly equalling that gem in the richness of its hue. It is not by any means easy to prepare glass of this color with any certainty of a successful result. The great tendency which is shown by gold to assume the reguline state, when exposed to excessive heat, to carbonaceous vapors, or to the action of hydrogen, renders necessary a great degree of careful management in the various processes.

The manner has already been given of preparing the purple precipitate of Cassius; the form wherein gold has been used with so much celebrity in imparting red and purple colors. It has been very generally imagined, that the tin used in the preparation of this precipitate is essential to the production of the requisite color; an opinion which has been shown to be void of foundation, as preparations of gold have been made without the agency of tin, and which have equally possessed the power of imparting the finest purple color to glass. The coloring property of any of the simple oxides of gold is found to be materially greater than that of Cassius's precipitate; which circumstance has been brought forward as another argument to prove that the presence of tin is far from adding any thing to the body of the color. It is probable, however, that, although not indispensable, tin is yet useful, as enabling the gold to bear without reduction a higher degree and a longer continuance of heat. With this same object, it has been recommended to add to the precipitate, before using it, a small quantity of nitre, by which the gold will be preserved at its due degree of oxidation.

It is not essential that gold used for this preparation should be absolutely pure or unalloyed; since neither copper nor sil-

ver, when present in small quantities, appears to alter or diminish its coloring power.

Fulminating gold, prepared by precipitating the metal from its nitro-muriatic solution by means of ammonia, is also used in coloring glass; but as this preparation would explode violently when exposed to a heat even very much below that to which it must be subjected in use, this explosive property must be previously removed by mixing it with a fixed alkali, and retaining it for some time at a comparatively low temperature. A more manageable preparation results from the precipitation of the nitro-muriate of gold by means of carbonate of potash. This is not fulminating, as it is from the presence of ammonia that the explosive property is derived.

A very ingenious process has been used for producing an intimate union between the oxide of gold and silex. This consists of adding to the solution of the metal in nitro-muriatic acid, a proportion of silica dissolved in an alkaline lixivium, and pouring therein any acid in sufficient quantity to saturate the alkali. In this case, the silex and gold are precipitated in very intimate combination; and if then washed with clear water, dried, and mixed with nitre, borax, or any other suitable fluxing substance, will be fit for use as a coloring material.

When the precipitate of Cassius is employed, about one sixth part of its weight is added of perfect white oxide of antimony. This, from imparting a yellowish tinge, is considered to be an important ingredient in fine ruby-colored glass.

The proper management of the heat employed in the production of this much-admired preparation is a difficult acquirement, known only to clever and experienced artists. If the temperature be allowed to rise too high, the color will be much injured, and probably even altogether destroyed. The contact of every kind of smoke and vapor should also be carefully avoided in the fusion of ruby-colored glass, which is said to be apparently colorless when it leaves the crucible, and only to put on its exquisite tint as it becomes cool.

Kunckel and other old writers upon the art of manufacturing glass have stated, that the coloring powers of the purple precipitate of Cassius are so considerable, as that one part, if added to one thousand parts of glass, will impart to the whole a full and rich body of color.

The artist just mentioned, who was greatly celebrated for his attainments in this ornamental branch of the art, was in consequence ennobled by Charles XI. king of Sweden, and assumed the name of Lowenstiern. He made artificial rubies, which were highly esteemed, and which he sold, in the manner of real gems, according to their weight, and at very consid-

erable prices. The achievement upon which he most prided himself, was the production of a cup of ruby glass, which was of the thickness of an inch, and weighed twenty-four pounds: this cup went into the possession of the elector of Cologne.

Kunckel directed, in 1679, the operations of the glass-houses at Potsdam, where he met with the greatest encouragement, and was liberally assisted in his researches by the elector of Brandenburg, who expended the sum of 1600 ducats to assist the efforts of the artist towards attaining perfection in the art of making ruby glass. A cup, with a cover of this material, which was made by him, and is still in existence at Berlin, continues to be an object of much admiration.

Silver, in all its forms of oxidation, imparts a very pure and beautiful yellow color to vitreous bodies; but this color is easily destroyed, through the accidental employment of too high a degree of heat; an evil against the occurrence of which it is so exceedingly difficult to provide, that silver is very seldom resorted to as a coloring material by glass-workers. The inconvenience here mentioned may in some degree be avoided when oxides of silver are used in combination with alumine, as in the ornamenting of porcelain; but this remedy is manifestly inapplicable to glass. Other bodies can, however, be used with the best effect in imparting a yellow color to this substance.

Oxide of lead employed alone, if in very considerable quantity, would give a very good yellow color; but as it would require that at least three fourths of the weight of the glass should be made up of this oxide, in order to give sufficient intensity to the color, it is very seldom used for the purpose. Glass thus formed would be inconveniently soft, and from its powerful fluxing quality would act injuriously upon the crucibles in which it was made.

Chromate of lead, which is not liable to the objections just mentioned, is on that account used preferably. Before the comparatively recent discoveries in chemical science had shown to artists in what manner to procure this valuable coloring ingredient with sufficient facility and at a moderate cost, the makers of colored glass employed the oxides of lead, silver, and antimony in combination, for the production of yellow colors; varying the proportions wherein each substance was used according to the hue which it was desired to impart.

Colors varying in their shades from brown to a fine transparent yellow may be given to common glass by simply adding to it, while in a state of perfect fusion, some vegetable carbonaceous matter. This must always be supplied in excess, since part of it, rising to the top of the crucible, will be burnt away; but some portion will also continue uniformly diffused through-

out the glass, and, without at all impairing its transparent quality, will give to it a very fine yellow. The substance which most commonly has been employed for this purpose is tartar; but almost any solid and inflammable vegetable matter will probably answer equally well. Charcoal made from beechwood is found to be altogether efficacious. The addition of a small quantity of nitre is sometimes useful in clearing the color and removing any cloudiness which it may have contracted; but if great discretion be not shown in the addition of this substance, the color will be altogether destroyed. During the time of its preparation, the glass swells very much in the crucible, owing to the escape of part of the carbonaceous matter in the form of gas; and when tartar is employed, this effect is experienced in an exaggerated degree. It is said that this effervescence might be avoided, if freshly burnt and perfectly dried charcoal were heated strongly in a close vessel, and added in that state to the contents of the crucible.

The oxides of iron give many and very different shades of enamel colors. It has already been mentioned, that the green color of common bottle-glass is owing to the presence of iron in the unpurified sea-sand and ashes of which it is composed. An increased quantity of this oxide, if applied to glass when in a state of perfect vitrification, will give a yellow color to the mass. A still larger quantity will impart a brownish black hue, which, however, appears to be nothing more than a yellow very highly concentrated, as the latter color may be again produced by simply diluting the contents of the crucible with an additional quantity of uncolored glass.

The red color which is imparted by the oxides of iron to porcelain, is owing to its state of imperfect vitrification, whereby the metal is held suspended in a state of minute division throughout the mass, which same effect is indeed apparent in the treatment of glass up to a certain point; but when in the advancing stages of vitrification the heat is raised so that a perfect fusion of the glassy substance as well as of the oxide is produced, the color is immediately converted to yellow.

The use of the black oxide of manganese in correcting the impurities of the alkali employed in the original composition of glass, as well as in removing the green tinge resulting from the presence of iron in the sand, has already been explained. Where these imperfections do not exist in the original ingredients, if manganese be added to the glass, it will impart a purplish red color. This oxide also forms a principal constituent in the production of black glasses: it is most commonly used in combination with nitre. If any portion of arsenical salts should be present in the glass, it is altogether useless to attempt the

employment of manganese as a coloring ingredient, since its efficacy would be wholly destroyed.

All the simple as well as the carbonated oxides of copper, when perfectly vitrified in conjunction with any kind of glass or fluxing material, will yield a very fine green, and the chances of complete success in the attainment of this are greater than attend the production of most other colors. It appears to be nearly a matter of indifference which of the combinations of copper with oxygen are employed for the purpose. The preparations most usually chosen are either the carbonated oxide resulting from the addition of sulphate of copper to some carbonated alkali, or that which is known as the *æs ustum*, which is copper oxidated and calcined simply by means of heat and the access of air.

Copper may be made to yield a carmine red color, and if mixed with iron, a full deep red, by adding to the glass with which it has already been combined a quantity of tartar. This addition must not be made until the glass is in a state of perfect fusion, and the mixture should be worked off without delay. It should be mentioned that when used for the production of these colors, the oxide of copper must be reduced to nearly the reguline state. If the heat is continued long after the tartar has been added, the effect will be lost, and the green color restored.

When the oxides of copper and iron are thus united for developing a full deep red color, the iron must be to the copper in the proportion of three parts to one; and according as this proportionate difference is lessened, so will the color be found to approach to the carmine tint.

The time for stirring in the tartar should be chosen when the melted glass appears of a faint greenish yellow; the whole mass will then immediately swell up prodigiously; and upon again subsiding will appear, as before stated, of a clear red color, and fit for being immediately used. It is probable that charcoal or other carbonaceous matters might be substituted for tartar in this process with equal success.

Copper in a state of oxidation is often used when combined with the oxides of manganese and iron for the production of black glass.

The protoxide of chromium may be used for producing a green color in glass, with as much advantage as attends its employment in the embellishment of porcelain, that substance being capable of sustaining without injury the highest heat of the crucible. Chrome is the natural coloring matter of the precious emerald, and is found to be a very valuable substance in the composition of artificial gems.

Oxide of cobalt is universally employed for the production of blue colors in vitrifiable bodies. The fine deep shade which it imparts is unalterable by fire of any degree of intensity, and succeeds equally well with every different composition of glass.

This metallic oxide is also employed towards the composition of other colors: combined with the oxides of lead and antimony, it furnishes a green; and if mixed with those of manganese and iron, produces a very fine black.

Neri, Kunckel, and Fontanieu have left in their writings many *recipes* for the preparation of artificial gems through the employment of different coloring materials. The directions, as given in the works of these authors, differ so importantly the one from the other as regards the proportions best fitted for the composition of the same article, that we are forced to believe either that some great errors have been committed on the part of their subsequent editors, or that the writers themselves were wanting in the kind and degree of knowledge to which they pretended, and which were required to fit them for the task they undertook.

A few of these recipes, and such as appear most free from this objection, may be here given.

The basis of each of these compositions is most frequently either one of the colorless glasses or pastes described in Chapter VII., or some other very similar vitreous compound; but it sometimes happens that the constituent materials of the glass, and the proportions wherein they are to be brought together, are indicated as well as the coloring substances.

The following is recommended by Neri, as furnishing a very excellent imitation of the garnet:—Rock crystal 2 ounces, minium 6 ounces, manganese 16 grains, zaffre 2 grains. This must be a very inconvenient composition, both on account of the exceeding softness of the glass, and the destructive effect it would have upon the crucible during the time of its preparation. We learn from the analysis of Berzelius, that the coloring matter of the "precious garnet," that being the variety which it is wished thus to imitate, consists of the black oxide of iron and oxide of manganese. A more modern recipe than the foregoing for the successful imitation of this gem, consists of purest white glass 2 ounces, glass of antimony 1 ounce, Cassius's precipitate 1 grain, oxide of manganese 1 grain; which composition is free from the objections to which that of Neri is so justly exposed.

The directions of Fontanieu for imitating the color of the amethyst are, that to 24 ounces of the glass composed according to instructions given in Chap. VII. under the number 5, are to be added half an ounce of the oxide of manganese, 4 grains of

the purple precipitate of gold, and $1\frac{1}{2}$oz. of nitre, but it is impossible to believe that the recipe of Fontanieu has been correctly given. The quantity of coloring matter here indicated would be better proportioned to 24 pounds of glass, than to the same number of ounces as directed.

Many, and greatly varying instructions have been given for imitating the emerald. Fontanieu recommends 160 parts of any glass basis which contains a large proportion of lead, 4 parts of oxide of copper prepared by simple calcination, and $\frac{1}{18}$th of a part of any oxide of iron; which last ingredient is added for the purpose of giving something like a richness of tint, and for correcting the coldness of hue that would result from the employment of the oxide of copper alone. The presence of lead in the glass would also conduce to the same end.

Another rule given from the same authority directs the use of 576 parts of glass, similarly constituted to that pointed out in the last receipt, 6 parts of the same oxide of copper, and only $\frac{1}{144}$th of a part of oxide of iron; thus differing from the former compound, only as to the proportions wherein the coloring ingredients are employed.

A third receipt for the attainment of the same object is very different from the two preceding. It recommends the employment of 200 parts of fine sand, 400 parts of minium, 8 of calcined verdigris, and as much as 1 part of oxide of iron. A fourth method for the composition of glass of an emerald green is, to mix, in due proportions, some blue glass colored by means of oxide of cobalt, with yellow glass prepared with oxide of antimony. A great many other prescriptions are offered for the imitations of emeralds, but these vary more in the relative proportions of their ingredients than in the principle of their composition; and it cannot, therefore, be necessary to insert them here.

The imitation of sapphires is always effected through the coloring agency of the oxides of cobalt and manganese. There is, however, a material difference as regards the basis of the glass in the various directions which are found for the purpose; one recommending that this shall be composed without lead, and another directing that this mineral shall enter largely into the composition of the paste. To 100 parts of glass of the first kind it is directed that 1 part of zaffre, and $\frac{1}{18}$th of a part of oxide of manganese, shall be added. Where the second description of paste is recommended as the basis, the artist is directed to prepare this by adding to 240 parts of glass frit made with only soda and silica, 192 parts of minium, 2 of zaffre, and $\frac{1}{3}$d of a part of manganese. This compound must be fused together,

poured into water, and then remelted as directed by Fontanieu, for the formation of the pastes described in Chapter VII.

The oxide of cobalt is, in the present day, a necessary ingredient in every imitation of the sapphire, so that it is never attempted to act without it. We have seen, however, that a very fine blue glass was formerly made having the oxide of iron for its coloring ingredient, and as it is known that the coloring property of real gems having that hue, resides in this metal when in some particular state of oxidation, we must own to having lost, in this respect, one means of imitating nature which was known and exercised by our predecessors.

The colored glasses comprised in the foregoing descriptions, are all translucent. The preparation of others, which have the opposite quality of opacity, is effected either by means of applying excessive doses of the same metallic oxides which, in smaller quantities, are used for imparting colors; or by the addition to those oxides of some other substance which has the property of obstructing the rays of light in their passage through the glass.

In general, the first method is used only for the production of black glass, while the second plan is pursued with all other descriptions, as well those which are designed to retain a permanent white color, as with yellow, blue, green, or any other colored opaque glasses.

The most approved method of preparing black glass, of good quality, which shall be of a full deep black and perfectly opaque, is by mixing together equal parts of black oxide of manganese, zaffre, and protoxide of iron; adding one part of this mixture to fifteen or twenty parts of colorless transparent glass, and fusing the whole together.

Some large and beautiful slabs of perfectly black glass have lately been imported into London from St. Petersburgh, and appear well fitted to be used as substitutes for marble in the construction of certain articles of household furniture.

White *opaque* glass, which has this quality imparted to it by means of the oxide of tin, is called enamel; and it is this substance of which the dial-plates of watches and of table clocks are commonly made. This compound is, however, too expensive for more ordinary uses, and a very good white glass is made for such purposes by substituting for the oxide of tin, a considerable proportion of phosphate of lime in the state of a very fine powder. This substance is procurable in great abundance, and at a moderate cost, in almost every situation. Phosphate of lime is extremely infusible, so that the opaqueness of the glass with which it is united, arises from its holding in intimate mixture an unvitrescible earthy salt.

One receipt given by Neri for producing white opaque glass is as follows:—Mix together 60 parts of fine white sand, and 40 parts of potash, with 10 of finely pounded bone-ash, and melt the compound during the same length of time as is usually employed in ordinary glass-making. It is said that this glass is transparent for as long as it continues at a full red heat; and that, as it gradually cools, it first puts on a milky appearance, and afterwards becomes wholly opaque. If this change does in reality take place, and is not rather the result of a deception which prevents the proper distinguishing of its degree of opacity while red-hot, it may probably arise from the circumstance that the excessive heat of the melted glass enables it to take up a greater quantity—in other words—to supersaturate itself with the phosphate of lime, which it parts with again in cooling.

Another receipt of the same artist is 130 parts of calcined flint or fine sand, 70 parts of nitre, 12 of borax, 12 of tartrate of potash, 5 of arsenic, and 15 of bone-ash.

Fontanieu has given directions for imitating the peculiar lustre of the semi-transparent opal, by mixing 576 parts of his glass No. 3. (Chap. VII.,) with 10 parts of muriate of silver, 2 parts of magnetic iron ore, and 26 parts of bone-ash. The beautiful play of colors exhibited by the "precious opal" is deservedly an object of much admiration, and it has always been a subject of interest to imitate successfully so pleasing an effect. Ornamental pieces of opal glass have usually been obtained from France; but their production, of a quality fully equal to these importations, may now be witnessed in the London glass-works.

The peculiar delicacy and beauty of this glass do not appear while it remains in a state of fusion or at a red heat, and are not fully developed until it is sufficiently cooled to have acquired its quality of brittleness.

Other colored glasses which are opaque, are made by the same processes as are followed with transparent glasses of the like colors, substituting for the common vitreous base, one of the above described, opaque-white glasses.

The ancients employed methods of converting colored glasses into representations of natural objects, which were extremely beautiful, and the manner of producing which is now lost. The existence even of this art is only known in these modern days from specimens which have been accidentally discovered; and our knowledge of the peculiar nature of their formation is wholly derived from the examination to which these specimens have been subjected.

The first mention made of these works of art is to be found

in the "Collection of Antiquities," by count Caylus, who described them as composed of delicate different-colored fibres of glass joined with the greatest nicety, and conglutinated into a compact homogeneous mass by fusion. Winkelmann, in his "Annotations on the History of the Arts among the Ancients," describes these same specimens as pictures made of glass tubes, and introduces them to further observation by these words:—"The works of the ancients in glass which are not noticed in the history of the arts, deserve particularly to be mentioned in this place, more especially because the ancients carried the art of working in glass to a much higher degree than we have arrived at; a fact which, to those who have not seen their works of this kind, might have the appearance of a groundless assertion."

The author just quoted particularly describes two small pieces of glass thus constructed which were brought to Rome in the year 1765, and which, indeed, appear to have been well deserving of his careful examination, as confirming the opinion he had given respecting the superior proficiency of the ancients. The account of these curiosities cannot be better given than in Winkelmann's own words:—"Each of them is not quite one inch long, and one third of an inch broad. One plate exhibits, on a dark ground of variegated colors, a bird representing a duck of various very lively colors, more suitable to the Chinese arbitrary taste, than adapted to show the true tints of nature. The outlines are well decided and sharp; the colors beautiful and pure, and have a very striking and brilliant effect, because the artist, according to the nature of the parts, has in some employed an opaque and in others a transparent glass. The most delicate pencil of the miniature painter could not have traced more accurately and distinctly either the circle of the pupil of the eye, or the apparently scaly feathers on the breast and wings, behind the beginning of which this piece had been broken. But the admiration of the beholder is at the highest pitch when, by turning the glass, he sees the same bird on the reverse, without perceiving any difference in the smallest points; whence we could not but conclude that this picture is continued through the whole thickness of the specimen, and that if the glass were cut transversely, the same picture of the duck would be found repeated in the several slabs; a conclusion which was still further confirmed by the transparent places of some beautiful colors upon the eye and breast that were observed. The painting has on both sides a granular appearance, and seems to have been formed in the manner of mosaic works, of single pieces, but so accurately united, that a powerful magnifying-glass was unable to discover any junctures. This cir-

cumstance, and the continuation of the picture throughout the whole substance, rendered it extremely difficult to form any direct notion of the process or manner of forming such a work; and the conception of it might have long continued enigmatical, were it not that, in the section of the fracture mentioned, lines are observable of the same colors which appear on the upper surface that pervade the whole mass from one side to the other; whence it became a rational conclusion, that this kind of painting must have been executed by joining variously colored filaments of glass, and subsequently fusing the same into one coherent body. The other specimen is of almost the same size, and made in the same manner. It exhibits ornamental drawings of green, white, and yellow colors, which are traced on a blue ground, and represent volutes, beads, and flowers, resting on pyramidally converging lines. All these are very distinct and separate, but so extremely small, that even a keen eye finds it difficult to perceive the subtle endings; those, in particular, in which the volutes terminate; notwithstanding which, these ornaments pass uninterruptedly through the whole thickness of the piece."

Klaproth, who had in his possession some specimens of these antique compositions in colored glass, compiled a paper upon the subject, which was read before the Royal Academy of Sciences at Berlin, in October, 1798; and the collection of antiquities formed by Mr. Townley, comprised a ring which contained a singular antique glass paste, which represented a bird of so small a delineation, as not to be distinctly visible without the aid of a magnifying lens, and which yet had every appearance of having been produced in the manner described by Winkelmann. Numerous antique specimens, similarly composed, are deposited in the British Museum. They are for the most part fragments, and it is to be regretted that we are without any records of their origin.

Keysler, the account of whose travels to different parts of Europe in the early part of the last century contains a great variety of entertaining and instructive matter, has given the following description of a mode of composing pictures in colored glass, which was at that time employed in decorating some of the churches in Rome. It will be seen that the method pursued by the Roman artists in some respects resembled that used for the composition of antique pastes, as described by Winkelmann. Recourse appears to have been had to this mode of producing pictures, in cases where the original paintings on wood or canvas were perishing through the dampness of the walls, and where it was wished to supply their places with copies composed of an imperishable substance.

"The materials used are little pieces of glass, of all the different shades in every tint or color like those of the fine English worsted used in needle-work. The glass is first cast into thin cakes, which are afterwards cut into long pieces of different thickness. Many of the pieces used in the works on roofs and ceilings, which are, consequently, seen only at a great distance, appear to be a finger's breadth; but the finer works consist only of glass pins, if I may call them so, not thicker than a common sewing-needle, so that a portrait of four feet square shall take up two millions of such pins or studs. These are so closely joined together, that, after the piece is polished, it can hardly be discerned to be glass, but rather looks like a picture painted with the finest colors. The ground on which these vitreous pieces are inlaid is a paste compounded of calcined marble, fine sand, gum tragacanth, white of eggs, and oil: it is at first so soft that the pieces are easily inserted, and upon any oversight may be taken out again, and the paste new moulded for the admission of other pins; but by degrees it grows as hard as a stone, so that no impression can be made on the work.

"This paste is spread within a wooden frame, which for the larger pieces must not be less than a foot in breadth and thickness. A piece of about eighty square feet, if performed with tolerable care and delicacy, will employ eight artists for two years.

"The pins of the several colors lie ready before the artists in cases, as the letters are laid before the compositors in a printing-house; and such is their accuracy in imitating the finest strokes of the pencil, that the only apparent difference betwixt the original painting and such a copy is, that the latter has a much finer lustre, and the colors are more vivid."

An accident occurred many years ago in the plate-glass works at St. Gobain, which seemed to offer the means of obtaining a bright red color for glass by the employment of copper, at a much less expense than has hitherto attended the production of that tint from gold.

It will be remembered that, in the manufacture of plate glass, when the refining is completed, and it is wished to transfer a portion of its contents from the melting-pot to the cuvette, a copper ladle is employed. It is necessary, while using this implement, to dip it occasionally into water, lest it should become too hot and warp, or possibly melt. On the occasion referred to, the workman having omitted this necessary precaution, the last of these misfortunes ensued; dipping the heated ladle once too often in the melted glass, only part was brought out attached to its iron handle.

It was imagined that the copper thus melted would sink, by

reason of its greater gravity, to the bottom, and would be found there in the metallic state on the emptying of the pot. The casting and annealing of the plates were proceeded with accordingly; and, on their completion, the workmen were surprised to find that not only were grains of metallic copper embedded in the substance of the glass, but bands uniformly colored of a fine bright red were distributed throughout the plates.

The color must, in this case, have been produced by the copper, which was suddenly carried to the degree of oxidation necessary for its development. M. Guyton-Morveau, when informed of this circumstance, was desirous of ascertaining, by direct experiment, what means would be most efficacious in producing the same effect. The result of his endeavors has been published.*

The first attempt was made with plate glass. In order to bring the glass and copper into more intimate union, the first was reduced to powder, and the other was used in the form of filings. The metal was used in the proportion of 3 parts to 100 parts of glass: this mixture was brought to a state of complete fusion before the glass was poured out. No success attended this experiment, the glass appearing uncolored, and the copper remaining mixed with it mechanically in the form of metallic globules.

The next trial was made with common white glass, mixed with twice the proportional weight of copper filings that had been employed in the first experiment. The compound having been completely melted, was found to have assumed a red color, which was uniformly diffused throughout the mass; but this color was so deep as to render the glass nearly opaque.

A trial made with copper, already in the form of an oxide, imparted a greenish color to the glass.

It is impossible not to remark that the circumstances under which these experiments were conducted, as detailed by M. Guyton-Morveau, differ in some essential particulars from those which accompanied the accident by which they were suggested. In that case, the glass was already in the state of fusion, and probably also in a high state of incandescence, before the addition of the copper. The proportion of metal used in the second experiment was evidently excessive; and it is surprising that the effect produced did not lead M. Guyton-Morveau to try the effect of a smaller proportion.

Attempts have been made to color glass by subjecting it to the action of heat, while surrounded by some cementing substances already impregnated with metallic oxides as coloring in-

* An. de Chim. vol. lxxiii. p. 132.

gredients. In most of these cases the glass remained perfectly colorless, unless the heat had been carried sufficiently far to induce devitrification; which state, as it renders the material opaque, furnishes sufficient objection to the use of this method of coloring. Even in those cases where transparency is not required, the same effect can be attained by easier means, and free from a very serious inconvenience, that of the adhesion of the cementing substance to the glass. Some curious facts connected with this subject will be detailed in the concluding chapter of this volume, which treats of the devitrification of glass.

CHAP. XIV.

ON THE ART OF STAINING AND PAINTING GLASS.

This Art more recent than that of Coloring.—Encouraged by the Monks.—Early Specimen at St. Denis.—Art never much cultivated in England.—Splendid Paintings at Gouda.—Directions given by old Authors for composing Colors.—Fluxes.—Vehicles for diluting Colors.—Description of various Stains.—Method of floating these.—Of painting on Glass.—Imitation of ground Glass with transparent Patterns.—Description of Kiln employed.—Method of firing.—Second and third firing.—Ancient method of fixing different colored Glasses on each other.

THE invention of the art of painting on and staining glass, although probably recent as compared with that of coloring the body of the metal when in fusion, is yet known to have existed for many centuries.

The exact period of its adoption is, indeed, involved in much obscurity; and it can, at best, be regarded as only a reasonable conjecture, which assigns its principal excellence, if not its origin, to the fostering care of those religious communities which, upon the breaking up of the great western empire of Rome, became, and for so long a period thereafter continued, the sole depositaries of learning and the arts in Europe.

Endowed by the piety or superstition of their unenlightened followers with revenues far beyond their personal wants, the clergy of that time expended a portion of their superfluous wealth in the construction of those splendid temples which attest to the present day the architectural skill and genius of their founders, remaining unsurpassed and almost unrivalled, in their kind as objects of admiration through a great portion of Europe. The ministers of a religion which addressed itself to the imaginations and the feelings of its votaries, they could not, perhaps, have adopted more effectual means for obtaining and perpetuating their influence over the multitude. Some idea of the ex

tent to which these means must have operated may be formed by every one who recalls to mind the sensations of solemnity amounting to awe wherewith he has himself been struck as he has stood beneath the lofty sculptured arches of a cathedral, or walked through its lengthened aisles, radiant with tints glowing through emblazoned windows.

The earliest specimens of these embellishments differ from those of more recent date in having been formed of small pieces of glass colored throughout during the process of its original manufacture, and which, to distinguish it from glass colored or stained by the methods that will be hereafter described, has been called by artists pot metal. Pieces of this, cut to the shapes required, were joined together in the manner of mosaic by the interposition of lead, in a way which has since fallen greatly into disuse; the method of staining and burning in metallic colors on the surface of the glass having been found far more beautiful, admitting of greater variety of tints, as well as of those delicate shadings which were manifestly unattainable by even the most laborious composition in mosaic work.

Perhaps the oldest existing specimen of this later-discovered art of painting on glass is to be seen on the windows of the abbey of St. Denis, whereon were recorded, in 1194, various events which occurred during the first crusade.

This art has never flourished to any great degree in England, where at no time have men of genius been much encouraged to apply their talents to its advancement: many among the most admired specimens of painted glass which ornament our religious edifices, are the productions of foreign artists.

The great church at Gouda, in Holland, is splendidly embellished with painted windows, which, about the year 1555, were executed by various artists, the most celebrated among whom were Dirk and Walter Crabeth. The one among the windows which is the most highly esteemed was painted by the first mentioned of these two brothers; and Mr. Hollis mentions, as evidence of the value placed upon this work of art, that for the lower part of this window,—about twenty feet square,—Mr. Trevor, some time English resident at the Hague, had in vain offered to give a solid plate of gold of the same surface, and of the thickness of three Dutch guilders.

This particular division of the fine arts differs from other branches in containing within itself fewer incentives to its prosecution. Its practice is accompanied by various laborious and differing processes. The range of subjects which it admits is far more circumscribed, and the opportunities which it offers for the display of excellence are far less frequent. The artist is even without the gratification of witnessing the satisfactory

progress of his own work, the appearance of which is comparatively dull and uninteresting until after it has passed from his own hands into those of "red Lemnos' artisan." The sculptor and the painter in oil colors can seldom fail in procuring means for exhibiting their works; so that, according to the degree of talent evinced by them will generally be their encouragement and reward; while the man who has conquered every disadvantage attending the processes of staining glass, and who may have produced a piece, the conception and execution of which are alike honorable to his genius and assiduity, might look in vain for the opportunity of bringing its merits before the world. These works have, therefore, seldom if ever been undertaken, unless at the requirement of others, who, dictating both the subject and its details according to their own peculiar tastes and wishes, leave nothing wherein the superior talents of the artist can be displayed, save the correctness of drawing and the elaborateness of execution. A man of genius will not consent to be thus trammelled, or follow, for the attainment of a precarious recompense, one profession, when, by bringing to the exercise of another the same amount of talent, and far less labor, he may at once give scope to his conceptions and advance his worldly interests.

A much wider field than presents itself for the exercise of this art in England, is certainly offered in Catholic countries, where not only is it more in accordance with the feelings of the people to ornament their religious edifices, but where a much freer scope is given to the artist in the choice of subjects for embellishment. Popular legends of the saints in honor of whom their churches are named, which are shut out by our simpler form of worship and severer religious discipline, afford a never-failing source whence these subjects may be drawn; while he who labors for the adornment of a Protestant church, is restricted to subjects founded upon mere scriptural authority. England has, indeed, within the last half century, produced some few proficients in this art, whose productions would do honor to any country: but the encouragement extended towards these talented individuals has been too limited to raise up, as in other pursuits, a succession of masters; while some, by whom it has at first been embraced, have been allured from it by the more general and liberal patronage accorded to the professors of oil painting.

Staining and painting on glass differ in some respects from all other styles of pictorial embellishment. They agree, however, generally with the processes used in painting porcelain, not only in the nature of the substances to be embellished, and in the materials whence the colors are derived, but likewise for

the most part in the methods used for the application of those colors, and in the necessity which exists for fixing them by exposure to a high degree of heat. The art is, indeed, in most particulars, so extremely analagous to the methods employed for painting porcelain, and which have already been treated of in this volume, that it will not be necessary to occupy much space in its description.

The colors are drawn from the same class of natural substances as afford enamel colors; they are prepared, and for the most part are applied, in the same manner; while any difference which may be found to exist in the mode of fixing and bringing out the effect of colors by the aid of fire, are more referrible to the varied forms of the articles than to any actual difference observable between the habitudes of glass and porcelain.

Boyle, in one of his letters on the subject of imbuing glass with metallic colors, wherein are detailed some experiments which he himself made in order to obtain a ruby color, relates also an anecdote of an artist, who wished, for some purpose, to prepare an amalgam of gold and mercury. With this view he kept the two metals for some time together in a state of fusion in a glass retort, when this at length burst with a tremendous explosion. Mr. Boyle adds, that he saw some of the fragments, and he declares them to be of the finest ruby color he ever beheld.

Many directions are to be found in the works of old writers for the composition of stains and colors. Some of these agree very closely with recipes in use at present, while others are evidently incorrect or incomplete; it being impossible, by following them, to obtain the colors which they are said to furnish. There appears to have always existed a spirit of exclusion on the part of professors of this art; and it has been said that this jealousy has even weighed with those among them who have written on the subject, so far as purposely to give false directions, that students might be deterred from the further prosecution of their attempts. It is more charitable, and at the same time more consonant with probability, to imagine, that the errors which abound in these works are owing rather to the carelessness of transcribers and editors, than to wilful misstatements on the part of the authors. Let this be as it may, it still is certain that until the period when M. Brongniart published the results of his experiments and practice in regard to enamel colors, the public was not in possession of any information whereon reliance could safely be placed for their production.

Various compositions are recommended to be used with the colors as fluxes, in order to promote their fusion when exposed

to the heat of the furnace: these compositions are termed hard or soft fluxes, in proportion as they require a greater or less amount of heat for their perfect fusion, and for the production of their full effect upon the metallic oxides with which they are joined. In choosing between them, regard must be had to the peculiar nature of the individual substance or compound wherewith they are combined, that the flowing of all in fusion may take place as nearly as possible together. With this view, it is evident that a waste both of time and labor would be experienced, if any hard flux were used with an oxide which could be brought to melt at a low heat; and, on the other hand, that it would be still more improper to use a soft flux with oxides which are more refractory, seeing that the proper incorporation of the two substances could not possibly in that case be occasioned.

Oxide of lead forms a principal ingredient in many fluxes. It is necessary, however, to be sparing in its use where it is required to produce pink colors, as these would be injuriously acted upon by any excessive quantity of lead. Its place may in such case be advantageously supplied by borax.

A fluxing compound, very generally used, is made by the union of thirty-two parts of flint glass with twelve parts of pearl-ash, and two parts of borax; which composition will fuse at a medium heat. If it should be required to render this more fusible, such an effect may be gained either by substituting for the pearl-ash four parts of red oxide of lead, or by increasing proportionally the dose of borax; and if, on the other hand, it is desired to produce a hard flux, this end may be attained by omitting the borax altogether, and adding an equal quantity of common table salt.

The directions for the preparation of fluxes for porcelain, which will be found in another part of this volume, apply equally to those which are to be used with glass, and it would be therefore useless to repeat them here.

When enamel colors are applied to glass, they are, besides their union with a fluxing material, mixed in the same manner as for painting on porcelain, with some substance as a vehicle for causing them to flow readily from the brush, and at the same time to prevent the colors from blending themselves one with the other during the operation. Oil of lavender, balsam of capivi, oil of turpentine or of amber, or sometimes gum-water, are employed as this vehicle. The choice of any particular substance must depend, as in the painting on porcelain bodies, upon the nature of the coloring matters employed, and is of no real consequence to the ultimate appearance of the glass, since

the whole will be entirely evaporated when submitted to the intense heat of the furnace.

The coloring compounds having been previously ground with an appropriate flux upon either a porphyry or strong plate-glass palette, by means of a muller of the same material, must again be ground in the same manner, and reduced to a proper consistency with the vehicle just mentioned. The artist will do well to prepare at first a sufficient quantity of every color required for the completion of the object which he has in hand; it being extremely difficult, if not impossible, to produce tints identically the same at any subsequent time, although the greatest attention be paid to the proportions of their ingredients. The injury which may be thus occasioned to the beauty of the piece need not be insisted upon.

Many objects may be painted on glass by persons who have not acquired any previous knowledge of the art of design. The transparent nature of the material enables the artist to see distinctly both the outline and the shading of any pattern which may be fixed upon its under side. The outlines of every such pattern should be decidedly given; and the whole contour and shading must be at once obvious when looking on its upper surface. When the pattern paper is laid horizontally upon the glass, it must be secured by wafers at each of its four corners, to prevent its shifting; the glass must then be placed upon an easel similar in form to a music-stand, and fixed steadily upon the table. Means should also be taken to prevent the slipping of the glass upon the easel, by passing a string across its face in any position that will secure this object, without interfering with the subject intended to be drawn.

To support the arm of the artist while he is employed in painting, as it would be improper for him to touch the glass, it will be necessary to use a rest stick, in the manner observed by artists who paint with oil colors.

It is considered advisable to trace the outline, in the first instance, with common Indian ink much diluted, before using for the purpose the pencil color, about to be described: the reasons for which are, that the strokes will admit of easier correction, and that a rough line will be thus formed upon the surface of the plate, which, drying immediately after the application, serves to direct the point of the brush when charged with the color, and to occasion the delivery of the latter with greater ease and regularity than would be otherwise attainable: by this means the artist may avoid any patching or altering of the outline, which would seldom fail to render the work rough and unsightly, but which must be resorted to if the lines prove unequal or imperfect. Faults of this kind may, indeed,

be partially corrected at any period of the process; but as the glass must be fired anew after each application of color, and as the firings constitute the principal part of the expense, it is of course advisable to exercise all possible carefulness, in order to avoid, as far as possible, the necessity for their repetition.

The color most usually employed for drawing the outlines and for shading different subjects, and which is therefore called by artists outline or pencil color, is made of the saffron-colored oxide of iron commonly known in the shops by the name of *crocus martis*. This oxide must be well ground in combination with an equal weight of soft flux upon a porphyry or plate-glass palette, as before directed, and subsequently also with oil of amber as its vehicle. To provide for the preservation of its proper degree of consistency, the addition of one or two drops of balsam of capivi may be needed; it is desirable, however, to make as sparing use as possible of this substance, which sometimes, when evaporated in the intense heat of the kiln, will, through its greasiness, indispose the glass from taking the color properly; and little vacancies may in consequence be left unoccupied, and requiring to be subsequently supplied. The pencil color thus prepared is a dark-reddish brown, and remains unaltered by the heat of the furnace. In order that the outline, while it is sufficiently decided, may at the same time be fine and clear, the pencil color must be used as little moistened as will admit of its flowing from the brush; and until it has become perfectly dry and hard upon the glass, no subsequent part of the coloring process should be commenced.

If when the pattern is wafered on the glass, and the outline has been completely traced, it is desired to make one or more copies of the figure upon other plates of glass, this may be done without removing the paper from the first, by simply placing the second and other plates in succession upon that to which the pattern is attached, the transparency of which will admit of the outlines being traced with the same facility as if the pattern had been transferred to each individual plate.

The best crown-glass is generally chosen for painting or staining, as being most transparent and free from color.

The colors must be laid on with a long-haired sable pencil; its handle must be of a length which will allow the artist to use his hand with freedom, and should be securely attached to the brush, so that the two cannot become disunited. If such an accident were to occur as the falling of this brush charged with color, it would be impossible adequately to repair the mischief by any means short of obliterating the whole, and beginning the work anew.

The shading and coloring are very frequently performed

upon opposite sides of the glass; and this condition is almost invariably observed where the color to be applied is one which can be made to flow with sufficient freedom, or, to use the phrase employed by artists, which can be floated on the surface of the glass. In cases, too, where it is desired to produce tints, such as many shades of green, which would result from the admixture of two different colors, this same effect is produced by applying one of these to the face, and the other to the reverse, of the glass.

There are only three colors, strictly speaking, which can be floated on, and which are called *stains*, to distinguish them from others which must be laid on by the strokes of a brush. These stains are orange, red, and lemon-yellow. They are composed according to the following recipes:—

Orange stain. Melt together in a crucible 2 parts grain or virgin silver, and one part of crude antimony. When cold, this compound must be pounded and sifted; and when used, must be mixed with 6 times its own weight of Venetian red, and diluted with cold water to the consistence of cream.

In floating this stain upon the glass, a large camel-hair pencil in a swan's quill, or a flat varnish brush of the same material, must be used. The glass should be taken in the left hand, while the other is employed in floating the color; the movements of the first being so managed, that the stain as it quits the brush may float gently and evenly over the surface. If, after this, the glass is placed upon a level table, the stain will dry in about twelve hours, when it is in a fit state for the kiln; and upon the application of a moderate heat, a deep gold-colored stain will be produced, which will have penetrated the substance of the plate, and which will continue unimpaired by time. A lighter-colored orange stain may be obtained by increasing the proportion of Venetian red, relatively to the quantity of silver and antimony.

Red stain. In no particular is the difference between ancient and modern stained glass more observable than in the absence from the latter of that brilliant scarlet tint, which is most generally seen on the first, and the art of producing which appears to be lost. The red color which artists are now accustomed to employ as a substitute for this, is tame and cold in comparison; and to give it any good effect, requires the aid of artifice, in placing it amid brilliant lights, or surrounding it with cold colors. The modern red stain is produced by adding, immediately before it is applied, three drops of sulphuric acid to each pint measure of the orange stain last described: precisely the same methods must be observed for the application of both.

Lemon-yellow stain. This is made by adding to 1 part of pure silver (precipitated) 12 parts of finely powdered pipe-clay. These must be mixed together in a basin with cold water to the proper consistence, and floated on as before described. The tint of this stain may be rendered lighter or deeper by adding to or taking from the proportional quantity of the pipe-clay. This, as well as the Venetian red, is of no effect in the production of color; they act only as vehicles assisting to spread the metals equally over the surface of the glass: of course, the greater their proportions, the smaller will be the quantity of coloring substance upon a given surface, and the lighter will be the resulting tint.

In addition to the above three stains, a fine transparent green may be also produced by first staining the glass on one side with lemon-yellow, and then painting it on the reverse side with a blue color. This combination will certainly not possess the same degree of clearness as is imparted by the simple use of either of the three stains which have been described, but it will have a good effect when used to represent foliage or for draperies in situations where recourse cannot well be had to the use of pot metal.

Where many colors are employed which must be laid on with a brush, the artist will apply some to the face, and others to the reverse, consulting his own fancy or convenience in regard to this disposition of the tints. The rule which forbids the application of another color, until one previously laid on shall be perfectly dry, applies in all cases, and must be observed as well in covering the opposite surfaces, as when various colors are applied to the same side.

When all the tints are laid on, and are thoroughly dried, the glass is ready for the first burning, the manner of conducting which will be hereafter described. After this has been performed, and the glass is removed from the kiln, the artist should proceed to scrape off the superfluous colors which remain upon its surfaces. If in the performance of this process care is taken to remove each one separately, these colors may be ground with a fresh portion of the vehicle, and employed on any future occasion, as their coloring properties will be perfectly uninjured. The costliness of some enamel colors renders this an object of some moment. On the completion of this scraping, it will be seen that the glass has been penetrated by the colors; and if due care has been taken in the choice and preparation of the coloring materials, and the previous processes have been properly conducted, there will be no necessity for any fresh application of colors: if even a few spots should appear, they will be removed by a second burning, which at the same time

will considerably heighten and bring out the colors. Should there, however, be any imperfections either in the stain, or painting, or pencil shading, these must be repaired by the artist previous to consigning the glass again to the kiln.

It is sometimes wished to give to glass the appearance of having been ground, leaving at the same time transparent lines or patterns upon its surface, the effect of which is very pleasing to the eye. In preparing for the production of this appearance, the artist uses a large camel-hair pencil, the end of which is dipped into oil of amber, so as to take up only a small quantity at any one time; and with this, holding the brush perpendicular to the glass, every part of the latter must be dabbed so that the surface will be dimmed by the oil. This must not lie thicker on one part than on another, and should by no means be applied in sufficient quantity to give it a fluid appearance. Taking then a mixture, composed of one part of white oxide of tin, with three parts of flux, previously well ground together, this must be sifted from a lawn sieve very gently over the glass, until the whole surface is evenly covered. The requisite quantity of this powder will adhere slightly to the glass through the means of the oil; and when, in the course of six or eight hours, this has become sufficiently dry, the superfluous powder must be lightly removed with a soft brush made of badgers' hair. The appearance of the glass will now perfectly resemble that which has been ground.

In order to produce lines or patterns upon its surface, that shall have the usual polish and transparent quality of glass, a pattern must be drawn upon paper, having its lines sufficiently strong to be visible through the powder; and this being fixed upon the reverse side, the artist with a blunt wooden instrument scrapes off the composition in lines accordant with those of the pattern. The plate of glass having then been subjected to burning in the kiln, it will be found that the powder has been partially melted by the heat, and is so firmly united to the glass, that its removal will be extremely difficult.

It now remains to describe the particular apparatus and process used for burning-in the colors which have been applied to the surface of the glass. The size of the kiln is of course dependent on the magnitude and number of the pieces of glass upon which it may be desired to operate at any one time. It would be unwise to construct one of larger dimensions than are likely to be needed in use, as the due heating of the glass is more difficult and expensive, in proportion as the relative size of the furnace is increased.

The glass is placed during the firing in a close iron box or oven, which is called a muffle, and which is provided with hori-

zontal iron shelves placed at regular distances apart, whereon the plates are deposited. The relative sizes of the muffle and furnace are such, that a space not less than four inches remains between the two on every side, by which means the fire may be made wholly to envelop the muffle. This receptacle is provided with a tube proceeding from its front, and narrowing towards its extremity, without-side the furnace wall, the use of which tube is to examine the state of the glass from time to time during the process of firing. The iron plates for supporting and separating the glass, and which are fitted to the shape of the muffle, are kept at their proper distances, usually about one inch asunder, by legs of the requisite length placed at their four corners. The shape of the muffle is usually wider at the top than at the bottom, so that pieces of various dimensions may be contained in its different compartments. The number of these bears reference to the size of the apparatus, some small muffles having no more than five or six, while others of greater dimensions are provided with double that number of shelves.

If the plates of glass were placed in immediate contact with the iron shelves within the muffle, the metal would have an injurious effect upon some colors. The iron is, besides, liable to be warped; and, when the glass was brought into a softened state by heat, would communicate its own distorted shape. Another and a greater evil than even these would arise from the too sudden variations of temperature whereunto the glass would be subjected, owing to the strong conducting power of the iron, and which would imminently endanger the cracking of the glass.

A perfect remedy for all these evils is found in previously preparing a smooth and even bed for the glass, by sifting pounded whiting to the depth of a quarter or three eighths of an inch over the entire surface of the iron shelves. Upon this bed the glass must be deposited with every possible care, so as to avoid rubbing the colors.

If more than one piece is committed to each shelf, they must on no account be brought into contact, nor must they be allowed to touch or even to approach within half an inch of the side of the muffle. When, after proceeding in this manner, the muffle has been filled, or all the glass that is ready for burning has been deposited, the cover must be put on to the muffle, and the fire lighted. It is usual to employ coke and charcoal as fuel for burning glass, both because they afford a steadier and more effective heat than coal, and because the sulphur which the latter so commonly contains might have an evil effect upon the colors.

The proper management of the fire in respect to the degrees of heat employed, is a thing which must be acquired through practice, it being impossible to give any written directions concerning it that will be efficacious. It may, however, be stated, generally, that caution is necessary in the first stage of heating, so as to avoid all suddenly great accessions of temperature; but that when, on inspection, the glass placed in the centre of the muffle is seen to have acquired a dull red heat, the fire may be urged with safety, so that the whole contents of the kiln may be made to acquire an uniform white heat. When this effect has once been produced, no more firing is requisite; the fuel which is already in the furnace must be allowed to burn itself out; and the kiln remaining thereafter closed, must be left to cool gradually during ten or twelve hours, before it is attempted to remove the glass: at the end of this time it may be considered properly annealed.

The process of the second or third firing is conducted in precisely a similar manner in all respects.

The same powdered whiting which has already served may be used again for an indefinite number of times, upon being ground and sifted as for its first application.

Specimens of ancient stained glass have been occasionally found, on parts of which the colors retain their full brilliancy, while on other portions they appear to be wholly obliterated; a circumstance which has excited some surprise; and no little ingenuity has been shown in the formation of theories to account for this partial disappearance of colors. There is reason to believe, however, that no decay has really ensued, but that, while some of the colors have been produced upon these specimens by processes similar to the foregoing description, other pieces of glass already stained in the manner of pot metal have been applied to uncolored parts, and made to adhere by the interposition of some fluxing material, which, being softer than the glass, has been decomposed in the course of time, and these adjunctive pieces have fallen away.

CHAP. XV.

ON THE ART OF CUTTING, ENGRAVING, AND ETCHING ON GLASS.

Origin of the Art of cutting Glass.—Implements.—Manner of their Employment.—Frosting.—Patterns produced by Moulding.—Engraving on Glass, executed with the Diamond.—Etching.—Schwanhard.—Difference of his Practice from that now used.—Method of Etching.—Fluoric Acid.—Glass Incrustations.—Origin of the Art.—Improvements thereon.

The art of cutting glass is a much more modern invention than that of painting and staining it, which has been described in the preceding chapter.

It is generally believed, that Caspar Lehmann, originally a cutter of iron and steel in the service of the emperor Rudolphus II., was the first person who attempted this mode of embellishing the material. It was about the year 1609, when, having procured from the emperor an exclusive patent for using the art, together with the appointment of lapidary and glass-cutter to the court, Lehmann prosecuted his invention with much success in the city of Prague.

Before that time, many artists had engraved figures upon glass, by means of the diamond; and their labors were greatly admired. Some glaziers had also discovered a mode of cutting glass by the employment of emery powder, and sharp pointed instruments of hardened steel, as well as with heated irons; but these methods were greatly different in the manner of their performance, as well as inferior in their effect, to Lehmann's process, by which they were consequently, for the most part, superseded. It was, however, very long after the period already mentioned, that the art attained to any thing like the degree of perfection which it now exhibits.

At the end of the seventeenth century, glass-cutting was prosecuted to a great extent, and in a very improved style, at Nuremburg; the artists of that place having much simplified the tools employed, as well as the methods used for their employment.

In the present advanced state of the art, the glass utensils and ornaments which contribute so greatly to the embellishment of our tables and saloons, owe much of their richness and brilliancy to the elaborate manner in which they are cut. This mode of ornamenting glass, although it does not indeed offer any field for exercising the higher faculties of genius and invention, yet calls for a considerable degree of taste in the arrangement of forms and figures.

The implements employed by the glass-cutter, although, owing to the great variety of the work which he has to execute,

they are of necessity numerous, yet partake of the simplicity observable throughout the various processes of the manufacture.

In some principal establishments, steam power is used for giving motion to a shaft which causes the revolution of numerous large wheels or drums fixed thereon, and each of these being connected by a band with a pulley on the axle of a smaller wheel, occasions the latter to revolve with great celerity: these small wheels are the cutting instruments. The occupation is frequently carried on in the apartment of an individual workman, and in this case, only one large wheel, similarly connected with the axle of one of smaller diameter, is turned by means of a winch, a boy being employed for the purpose. In all other respects the process is identical, whether prosecuted in the attic of the artisan, or in the spacious factory of the manufacturer.

The small wheels are so arranged, that each can be unfixed without difficulty, and another substituted of a form better suited to the work in hand, or of a material more adapted to the stage of the process.

As regards their forms, these cutting wheels are either narrow or broad—flat-edged—mitre-edged, that is, with two faces forming a sharp angle at their point of meeting—convex or concave. In fact, so various are the wants of the workman, that as many as forty or fifty wheels having differently shaped edges, are to be found in the workshop.

The materials employed in the formation of these cutting implements are, iron, both cast and wrought; Yorkshire stone; and willow wood. Wrought iron is, indeed, only used for cutters of the narrowest dimensions, and which it would therefore not be possible to make sufficiently tough of cast metal. Iron wheels are used only for the first or roughest part of the operation, and their employment is even dispensed with altogether, where it is intended that the pattern shall be at all minute; as the metal and the sand, which must be used in conjunction with it, would act too roughly, and frequently chip away portions of the glass. For such minute works, and for smoothing down the asperities which will always be occasioned where iron cutters have been applied, a wheel of Yorkshire stone, moistened with water, must be used. The further smoothing and subsequent polishing of the cut surfaces are effected with wooden wheels: for the first of these objects, the edge is dressed with either pumice-stone or rotten-stone; and for imparting the high degree of polish that is requisite for properly finishing the process, putty-powder is employed.

Beneath each one of the cutting wheels, a small cistern is fixed to receive the sand, water, or powder which has been used; and over the wheel, a small keg or a conical vessel is

placed, the cock or opening at the bottom of which is so situated and regulated, as that the requisite quantity of moisture will be imparted from it to the wheel. The vessel which is placed over the iron wheel is furnished with fine sand, and into this water is admitted in such quantity as will insure the constant delivery of the moistened sand upon the face of the wheel in such proportion as the workman finds most desirable. The emery powder, rotten-stone, or putty-powder, are applied from time to time as required by the workman, on the edge of the smoothing or polishing wheel.

From this short description of the implements, the manner of their employment will be readily comprehended. The glass-cutter seats himself on a stool in front of the wheel; and taking in his hand the glass to be ornamented, applies this to the face of the cutter, the correctness of his eye and the steadiness of his hand being called into requisition, in the successive applications to the wheel, of those parts of the glass that are to be cut. Placed at his right hand each workman has a small tub containing water, wherewith from time to time he washes away the particles of sand or powder which may adhere to the glass, that he may the better judge as to the progress of his work.

It may readily be supposed that, in conducting a process of this nature, with so exceedingly brittle a substance, accidents will often occur through the breaking of the material. The frequency of these casualties will of course depend, in a great measure, upon the original quality of the material; and this forms one reason why the best description of glass is generally chosen for the purpose of being cut.

In fitting up the machinery, it is plain that the utmost accuracy must be exercised. If the cutting-wheels were allowed to turn upon their centres with the smallest degree of eccentricity, it would be quite impossible for the operator to proceed with any regularity in his work, or to produce a satisfactory effect.

The wages of glass-cutters, in common with those of men employed in the different manufacturing processes of a glass-house, are paid according to the work which they deliver in a finished and perfect state; so that if any accident should occur to the glass while in their hands, as is frequently the case, the workmen cannot claim any payment for the labor which they may already have bestowed upon it. Every man who follows the occupation of a glass-cutter is capable of executing each part of the process, although some will succeed better in one branch than in others. In large establishments there is generally such a choice of work, that every workman has the opportunity of providing himself with employment in that branch

which he prefers; besides this, two or more men, forming a sort of partnership, will frequently undertake work in conjunction, each of them performing that branch of the process which he feels himself qualified to execute with the greatest success, by which division of labor the whole work is more expeditiously and probably also more satisfactorily performed.

The grinding of glass, or *frosting* it, in order to lessen its transparency, forms a branch of the glass-cutter's art. The objects to which, in the present day, this grinding process is most commonly applied, are shades for softening the light diffused by table lamps. As the roughness is given to the inner surface of these glasses, it is plain that they cannot be applied to the cutting-wheel for the purpose. Instead of this, the shades are, therefore, fixed in a lathe, and the workman, holding in his hand a piece of wood which he covers with wet sand, causes this to rub with the necessary degree of force against the inner surface during the rapid revolutions of the glass.

The amount and description of labor bestowed upon articles which pass through the glass-cutter's hands, must necessarily enhance their money value, and therefore circumscribe their use. Nor is there much reason to look for the discovery of any improvements in the processes whereby that labor can be so abridged as that the manufacture will be brought within the reach of a larger number of consumers. Under this view, any method of ornamenting glass which can be offered as a tolerable substitute for cutting it, is likely to be favorably received by the public.

Such an invention has recently been made the subject of a patent, under which glass vessels, having a variety of shapes, are formed with ornamental figured patterns impressed upon them.

The method of producing these patterns is sufficiently simple, and consists in placing a quantity of melted glass within a metallic mould of the required form, in the lower division of which the desired pattern is engraved; and in then bringing down the upper section of the mould, and pressing the melted glass between the two. The only skill required for the operation is that of apportioning rightly the quantity of melted glass which is required for exactly filling the mould, so as to take a faithful impression of the engraved pattern. The two parts of the mould are connected together by means of a hinge, and the upper portion is provided with a long handle, which acts as a lever for imparting the requisite pressure. The lower section is composed of two pieces, which being opened, the glass

may be removed from the mould almost at the moment of its formation.

Intended as a substitute for cutting, this art must certainly be considered inferior. The patterns imparted by the mould are deficient in the degree of sharpness which is imparted by the wheel. On the other hand, a description of ornament may be thus adopted, which is otherwise unattainable; the figures may be either raised or depressed, and patterns the most minute and intricate may be produced. Armorial bearings, in particular, may thus be represented, in a manner far superior to any engraving, not only as the glass will everywhere retain its polish, but also because figures may be given in relief. Between the cost of the two processes there cannot be any comparison.

Many specimens are preserved in collections of ancient glass which are ornamented with raised figures. These have been most probably produced by pressure within a mould while yet softened by heat, such a practice being one of great antiquity. Engraved figures were likewise executed upon hollow vessels by the old Greek artists; and that celebrated engraver on stones, Lawrence Natter, affirms, in his "Treatise on the Antique, when compared with the Modern Method of Engraving on Precious Stones," that the same kind of instruments were used for the production of these relics of antiquity, as were employed for the same purpose at the time when he wrote. He considers that the old artists undoubtedly used a wheel, which moved in a horizontal direction above the table at which they wrought; and this opinion is in agreement with a passage in Pliny (Hist. Nat. lib. xxxvi. cap. 26.):—"Aliud flatu figuratur, aliud torno teritur, aliud argenti modo cælatur." On the other hand, to agree with Natter would be to deprive Lehmann of his reputation as an inventor, although he may still be entitled to the honor of having revived an art which had become obsolete; and this, in the opinion of the learned antiquarian Caylus, himself the re-inventor of a sister art, is the amount of merit whereto Lehmann may justly lay claim.

In the middle of the sixteenth century, when glasses manufactured in the Venetian states enjoyed the highest reputation throughout Europe, it was common to find these ornamented by engravings executed with the diamond. More than an hundred years had elapsed from that period, when Henry Schwanhard, a pupil of Lehmann, was incited by the accidental circumstance of the corrosion of his spectacle glass, to a method of etching on glass by means of some powerful acid liquor. His manner of preparing this liquor was kept secret by him; and as no fluid, save fluoric acid, with which we are acquaint-

ed, has the property of acting upon the surface of glass, while the discovery of this powerful menstruum was not brought before the world prior to the publication of Scheele's experiments in 1771, it is much to be regretted that the secret of Schwanhard was suffered to go with him to the grave.

The method pursued by this artist in the application of his discovery was different from that which is practised at present. This is, to coat over the entire surface of the glass with varnish, and, through this coating, to trace out the intended figures, leaving the glass exposed to the action of the acid only in those parts which are to be occupied by the figures. Schwanhard, on the contrary, first traced the figures, and, having filled the outline on the glass with varnish, applied his corrosive fluid to the remainder of the surface. By this means the figures were left in relief, and with their original polish, the effect of which was pleasing, and totally dissimilar to the appearance of engravings with the diamond, which latter circumstance it probably was that incited the artist to the adoption of his peculiar method, since his productions would, by that means, be more readily distinguished from the works of others.

The varnish employed by artists for defending, where it is requisite, the surface of the glass from the corroding power of the acid, is usually either a solution of isinglass in water, or common turpentine varnish mixed with a small proportion of white lead.

By the aid of a very few implements, the art of etching on glass may be rendered a pleasing occupation for amateurs. Good crown-glass is the most proper to be chosen for this purpose. Having selected a square pane of the proper size, this should be first heated by immersion in a sand-bath, and then rubbed over with purified bees'-wax, the temperature of the glass being such as to cause the wax to melt completely and uniformly over its surface. The pane, thus covered, must then be set aside to cool; and it is important to observe, that every part of its face must be protected by this coating of wax; which, however, need not be thick, and indeed should not be applied in sufficient quantity to render the glass opaque.

A paper having the design boldly drawn upon it, may then be attached to the unwaxed under side of the glass; and this drawing will greatly assist the artist in performing the next process, that of tracing the design through the wax. The best kind of tool for executing this operation is a carpenter's bradawl, which, as it is flattened at the end in one direction, and rounded in another, may, according to the position wherein it is held, be easily made to trace lines having the requisite and different degrees of fineness. The point of a penknife, or any

similar implement, may be used as a substitute for the brad-awl, and with almost equal efficacy. In tracing these lines, the artist must be mindful that his instrument lays bare the surface of the glass throughout the whole extent of the strokes.

A shallow evaporating basin of Wedgwood ware must next be employed. Its size should be such as will include within its area every part of the design; and it must at the same time be sufficiently small to be completely covered when the pane of glass is made to rest upon its edge. Some coarsely powdered fluor spar must then be placed in the basin, together with a quantity of strong sulphuric acid, sufficient to form with it a thin paste, when the two substances must be well mixed together by stirring them. The quantity of fluor spar must of course be regulated by the size of the etching; and it may be a sufficient guide on that head, to recommend that two ounces of the coarse powder be used when the basin is capable of containing a pint: these basins are readily procurable from any respectable dealer in earthenware.

As soon as the acid and fluor spar are properly incorporated together, the pane of glass should be placed upon the basin, with the waxed side downwards, and a moderate degree of heat must be applied to the bottom of the basin: somewhere between 120 and 140 degrees of Fahrenheit's scale will be found most eligible. Perhaps the best means of providing a steady heat for this purpose is offered by the sand-bath, which was used for heating the glass before applying the wax. On this subsequent occasion, however, the temperature must never be sufficiently high to melt the wax, which in that case would run over the glass, and wholly destroy the effect of the etching.

Very soon after this application of heat, fumes of fluoric acid will rise copiously from the basin, and attack the unprotected portions of the glass. When the basin and its contents are once thoroughly warmed, the heat of the sand-bath may be advantageously diminished.

After the glass has been thus exposed during half an hour, it may be removed from the basin; and first being rinsed in water, for the purpose of diluting or washing away the fluoric acid, the wax may be scraped off with a common table-knife; the design will then be found perfectly etched upon the surface of the glass.

A metallic basin will answer perfectly for generating the fluoric acid; but it will be altogether improper to use any glazed vessels for the purpose, as the vitreous coating of such would be entirely destroyed.

In performing this process, it is necessary to use some caution; as fluoric acid, if brought into contact with the skin, will

quickly disorganize it, and produce wounds which may be painful and troublesome; a very little carefulness will, however, suffice for preventing any accident of this nature.

When it is required thus to engrave other than plane surfaces, another arrangement must be provided: the glass must be exposed to the fumes of fluoric acid in some deep vessel; without, however, being suffered to come in contact with the pasty compound whence the acid fumes arise; and the whole should be covered over, to confine and retain those fumes, so that they may fully act upon the glass.

Articles made of flint glass are sometimes very tastefully ornamented, by inclosing within their substance various objects formed out of bodies which, being less fusible than glass, will not be altered in their form or nature by the heat contained in this at the moment of their introduction.

The art was first attempted about fifty years ago, by a glass manufacturer in Bohemia, who sought to incrust small figures made with a grayish kind of clay. His success in this attempt was but moderate; the material of which he made choice for his figures, expanded and contracted very unequally with the surrounding glass, and their adhesion to it was consequently imperfect.

The successful accomplishment of this pleasing art has long been a favorite object with the French manufacturers, who have been unsparing of expense in their efforts for its perfection. For a long time, however, their success was small, and the specimens produced by them were so costly, that but little encouragement was offered on the part of purchasers. The subject at that time principally chosen for the exercise of this art, was a medallion of Napoleon, whose courtiers evinced the desire of possessing his likeness in this imperishable form, as being emblematic of their own unalterable attachment! Improvements have since been made by the French artists, which have enabled them to reduce the cost of these incrustations within more moderate bounds; but their manufacturers have hitherto mostly restricted themselves to the ornamenting in this manner of scent-bottles and trinkets.

A few years ago one of the most considerable London glass manufacturers discovered the means of attaining to a higher degree of success, and is now enabled thus to ornament, in a very tasteful manner, various objects of considerable size; employing for the purpose substances whose property it is to expand and contract equally with glass upon exposure to altered temperatures. This interesting art can by this means be applied to represent ornaments of almost every description. The appearance most usually given to them is that of silver; but as the

metallic oxides may be employed for coloring the substances previous to their incrustation, every variety of hue that can be used in enamel painting may also be imparted.

CHAP. XVI.

ON THE DEVITRIFICATION OF GLASS.

First observed by Neumann.—Experiments of Reaumur. Substance known as Reaumur's Porcelain.—Inappropriateness of this name. Uses to which the Substance may be applied.—Common Bottle Glass most proper for the Conversion.—Method of effecting the Change. Produced solely by Heat.—Experiments of Dr. Lewis.—Revitrification. Experiments of Sir James Hall.—Proposal suggested thereby.—Observations of Guyton Morveau. Artificial Intaglios.—Mock Onyxes. Power of Devitrified Glass to bear sudden Changes of Temperature. Experiments with Colored Glass. Glass devitrified by burning Lava. The Process promoted by [illegible] ing the Ingredients of Glass.—Devitrified Glass conducts Heat more perfectly than when vitreous.—Becomes a Conductor of Electricity. [illegible] this Property when revitrified.

It was observed very long since by Neumann, that some kinds of glass, if exposed during any [illegible] high degree of heat, but below their point of [illegible] changed in their properties and texture [illegible] fibrous, and tough; and so hard as to [illegible] struck with steel, to cut any common [illegible] scarcely susceptible of [illegible] found, that in taking this form, [illegible] regards its qualities of [illegible] it will bear a sudden [illegible] water.

That indefatigable [illegible] experiments and [illegible] year 1739, communicated [illegible] emy of Sciences [illegible] more generally [illegible] and has since [illegible] nation which [illegible] properties, [illegible] celain. [illegible] the substance [illegible] wards a [illegible] ten [illegible] number of [illegible] investigation [illegible] [illegible]

of that one which would insure the concurrence of the greatest number of good qualities that should be found in porcelain. The futility of these experiments has since been made evident; and it must be regretted that the same amount of research as was thus unprofitably bestowed, has not been given to elucidate the actual properties of devitrified glass, and to render it practically serviceable to society.

Reaumur was of opinion that its quality of resisting alternations of temperature, its toughness, as well as the power it possesses of withstanding the action of acid liquids, render this porcelainous glass well qualified for the formation of chemical vessels. The same opinion has been equally held and declared by other philosophers who have brought their minds to the investigation of the subject; and it appears singular that their suggestion should not, consequently, have been very generally reduced to practice. This circumstance must further excite surprise, when it is considered in how many important operations of the laboratory such a substitute for metallic vessels would be advantageous. In operating upon any practical scale, the chemist is driven, for want of such a substitute, either to the employment of metals which are liable to be injuriously acted upon by the matters under process, or is compelled to adopt vessels of platinum, the expensiveness of which places them beyond the prudent reach of most persons. In one instance, a manufacturer of pharmaceutical preparations, who is exceedingly particular as to the absolute purity of his productions, has recently incurred the expense of constructing a pan of unalloyed silver, forty inches in diameter, wherein to evaporate vegetable extracts, many of which, in some degree or other, act upon and are impregnated by copper.

Could vessels formed of this fibrous glass be adopted with safety, there would be nothing in their cost, especially when of moderate size, to prevent their general adoption. The only circumstance hitherto assigned against this adoption is, that although the inner texture of the glass is fine and white, the surface is coarse and of a dirty appearance; but this must be thought a very insufficient cause for foregoing such decided advantages as are apparently offered through its employment.

All kinds of glass are not equally qualified to undergo this conversion; with some descriptions, indeed, it will not ensue. Not any vitreous compound seems altogether proper for it, with the exception of common green bottle-glass, and perhaps also the ordinary kinds of window glass.

The method commonly employed for effecting the change is as follows:—The glass vessel is placed within a larger earthen vessel, in the same manner as is pursued for baking porcelain.

The entire space unoccupied by the glass is next filled by pouring into the vessel fine white sand, or powdered gypsum, so that the glass shall not be allowed at any point to come into contact with the earthen case. The containing vessel is then covered down, securely luted, and the whole is placed within the furnace.

It was for some time generally imagined, that in this process, which is very similar to that which is known to chemists under the name of cementation, the glass owes the change which it undergoes to some chemical action of the gypsum upon its substance: but this has been proved erroneous. It is shown by Dr. Lewis, in the detail of his various experiments, that not only may the nature of the powder be almost infinitely varied, without in the least affecting the operation, as far as regards the altered texture of the glass, but that the change equally and identically goes forward in the absence of all cementing substance; a fact which is conclusive upon the subject, and which proves that whatever may be the particular substance employed, whether sand, bone-ash, chalk, or gypsum, it acts merely by affording mechanical aid, sustaining the glass in its proper form during the period when it is softened by heat, and when, if deprived of such support, it would be liable to irreparable injury in falling together by means of its own gravity.

In the course of experiments, which are detailed by him at some length,* Dr. Lewis placed several pieces of common wine bottles into crucibles, pouring over them the requisite quantities of white sand, and placing them in a proper furnace, wherein they were heated during many hours. In order to ascertain the progress of the change, pieces were withdrawn from time to time for examination. Those pieces which were first taken out, after having been during several hours in the furnace, but without being heated to redness, exhibited no sort of change whatever. In a low red-heat the change went forward very slowly, but still was quite perceptible; while in a strong red heat approaching to whiteness, and which only just avoided that degree of intenseness which would have melted the glass, the change went on rapidly, beginning at each surface, and spreading towards the middle; so that, in two hours, the substance had assumed throughout the appearance of porcelain.

The glass became first of a bluish color on the surface, and exhibited a very sensible diminution of its transparency. After this, it gradually became white and more opaque; the texture no longer continued vitreous, but became fibrous, as already described; and these fibres were disposed nearly parallel to each

* Commercium Philosophico-technicum, p. 150.

other, and transverse to the thickness of the piece. The fibres from both surfaces meeting in the middle, formed there a kind of partition, in which cavities were occasionally perceptible. By degrees this opacity and fibrous change were completed, the blue color disappeared, and was succeeded by a dull white or dun color.

When exposure to the same high degree of heat was continued after the production of this effect, the glass was seen to undergo a still further change of texture: the fibres appeared to be divided or cut into grains; beginning, as before, at the outer ends, and proceeding onwards towards the middle, until the entire substance assumed a granular form, similar to ordinary porcelain. A still further continuance of heat caused the grains, which at first were fine and glossy, to become enlarged and dull, and to change from a compact to a porous, and at length to a friable substance, resembling a slightly cohering mass of white sand, not easily distinguishable from that wherein it was embedded.

If glass, which has been withdrawn from the furnace at the time it has assumed the fibrous state, be afterwards subjected to a very strong heat, it will melt into a semi-transparent mass, and may be drawn out in strings, which on cooling are found to have lost their fibrous quality, and to have resumed their former vitreous state, being no harder than before the original cementation. This fusion of porcelainous glass cannot, however, be effected, without the application of a degree of heat considerably more intense than is required for melting glass in its more usual form; and it is also found that the farther the process of cementation has been carried, the higher must the temperature be raised for its fusion; so that specimens which have been rendered granular are much more refractory than such as are simply fibrous.

Although, throughout the experiments of Dr. Lewis, no difference in the actual properties of Reaumur's porcelain followed the employment of different substances for embedding the glass,—its internal color, hardness, texture, and the regular succession of its changes being the same in all cases;—yet considerable difference was occasioned in its outward color. If charcoal or soot had been used, these produced a deep black color, which was not affected by long exposure to heat in an open furnace. Clay or sand which was colored, communicated different shades of brown; and white earths gave either gray or brown tinges. The greatest degree of whiteness followed upon the use of white sand, calcined flints, or gypsum; and the highest state of glossiness or brightness was caused by the employment of pipe-clay.

In the account published by Sir James Hall of his highly interesting course of experiments on the effects of compression in modifying the action of heat upon a certain class of substances, incidental mention is made of an important circumstance connected with this change in the texture of glass, and which seems to point the way towards the institution of a further course of useful investigations.

Having placed in the closed end of a porcelain tube a portion of the substance which he was about to subject to the action of heat under pressure, it became necessary to introduce likewise within the tube some other substance, which could be brought to such a state as would oppose an effectual barrier against the communication of the principal substance with the atmosphere. The use of various bodies was attempted for this purpose, and each was successively rejected as inadequate. Among these, Sir James determined upon trying the effect of pounded glass; which, being placed within the tube, above and nearly in contact with the principal substance, could be subjected to such a degree of heat as would fuse the glass, while the closed end of the tube might be sufficiently withdrawn from the action of the furnace; and when, in the prosecution of the actual experiment, this end should come to be placed in the strongest heat, that portion of the tube in which the then compact body of glass was contained could be equally removed from a temperature which would again alter its form.

The description of glass accidentally chosen by Sir James Hall for his experiment, was that which is best of all qualified for conversion into Reaumur's porcelain. Having introduced the tube wherein the pounded glass was contained within a muffle heated to the temperature of 20° of Wedgwood's scale, 3677° Fahrenheit, he discovered, that in the space of one minute it entered into a state of viscid agglutination, similar to that of honey; and that when only one more minute had elapsed, the entire particles were consolidated into a firm compact mass of Reaumur's porcelain: during the short period here mentioned, the heat of the muffle had been uniformly sustained at the same degree.

If a solid cylinder of glass, having the same bulk as the powder thus placed within the tube, had been exposed to the same temperature, it would equally have undergone a change from the vitreous to a fibrous state; but the time required would have amounted to at least an hour.

The result of the discovery thus unexpectedly made by Sir James Hall, renders it probable, that if common green bottle-glass, previously ground to powder, were introduced within appropriate moulds, and exposed to an adequate temperature, it

would speedily and satisfactorily be converted into vessels of Reaumur's porcelain; and by this means, not only would the time expended be materially abridged, and fuel economized, but the manufacturer would be relieved from one of the greatest practical difficulties which has been found to attend the conversion, and which arises from the tenacity wherewith the sand usually employed is found to adhere to the glass.

This evil is frequently experienced to so great a degree, that the force required for their separation endangers the breaking of the vessel. Moulds of every requisite form might be made without difficulty, of substances sufficiently refractory to remain uninfluenced by the temperature employed for the conversion, and which would deliver the glass freely upon its completion.

M. Guyton-Morveau read, in 1810, before the French National Institute, a paper containing observations with a view to explain some phenomena that occur in the fabrication of glass.* In the course of his remarks, this celebrated chemist drew the attention of his auditors to several specimens of devitrified glass collected by him, which had been rendered opaque and fibrous by the long-continued action of heat in a porcelain furnace. Some of these pieces were converted, without having been surrounded by sand or gypsum, or any other cementing substance, and yet exhibited the completest change throughout their substance.

One of his specimens, composed of bottle glass, had been exposed, during three entire days, to the heat of 50 degrees of Wedgwood's pyrometer, and had acquired interiorly a rosy tint, its fracture exhibiting fibrous lines, arranged in the form of stars, and converging towards the centre: this glass was sufficiently hard to scratch rock crystal. Another specimen of flint glass, which had been exposed during the same time, in the same furnace, exhibited only the commencement of crystallization at its surface; the interior retaining, unaltered, its original vitreous quality.

M. Guyton-Morveau likewise exhibited some artificial intaglios, made of bottle glass, which had been first softened and moulded in a cupelling-furnace, on an impression taken with rotten-stone, and subsequently devitrified in the heat of a porcelain furnace. These specimens were sufficiently hard to scratch rock-crystal; a quality which points out the fitness of such productions to be used as dies for the preparation of intaglios and cameos, the impression which they receive and impart being exceedingly chaste and perfect. The same quality suggests the advantage that would probably be found in the em-

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* Ann. de Chim. vol. lxxiii. p. 113.

ployment of Reaumur's porcelain in the composition of mock onyxes; but, for this purpose, the ground and figures must be formed of separate layers of different-colored glass, which must be brought together by means of some fluxing material, and afterwards devitrified, in order to give them the requisite opacity, and, in some degree, also, that hardness which is the distinguishing characteristic of gems.

One specimen, also brought forward on the same occasion by M. Guyton-Morveau, was a segment of a globe, composed of bottle-glass, which had been cut in the form of a watch-glass, to be used as a capsule, and afterwards devitrified. This piece might be suddenly heated red-hot, and immediately thrown into cold water, without experiencing injury. It might also be kept in heated sulphuric acid, without exhibiting the least corrosion or alteration of weight; two qualities calculated to render its employment eminently advantageous for the purposes of chemical analysis.

The result of different experiments made to devitrify stained glass taken from church windows, was likewise shown, on the same occasion, by M. Guyton-Morveau. Of various pieces thus treated, some were colored red by the precipitate of Cassius, and others blue by oxide of cobalt. One of the red specimens contained lead in its composition; this, on losing its transparent quality, had become of a spongy consistency, and appeared full of blebs; in the other piece, which was hard crown-glass, the devitrification was seen to have pursued its usual and regular course, interiorly from the two surfaces: it had acquired a purple tinge, and was so little hardened that it might be scratched by rock-crystal. The piece which had been stained by oxide of cobalt differed from the last in more than one particular. Its hardness was so great, that scarcely could any perceptible mark be made upon it by adamantine spar; its blue color, which had the appearance of being somewhat weakened internally, was at the same time more intense at the surface, a variance which might, indeed, be more apparent than real, and which probably resulted from the greater opaqueness it had acquired at that part; as although the glass had lost all transparency, the devitrification was by no means perfect, having proceeded but a short distance below the surface.

Glass has been converted into Reaumur's porcelain during volcanic eruptions, by being enveloped in burning lava. Some specimens of this kind were obtained after the destruction of Torre del Greco, in 1794; but it is somewhat remarkable, that this devitrifying effect has been by no means uniformly exhibited under the same circumstances, since pieces of glass have been found, which, although completely embedded between two

opaque volcanic crusts, yet retain their transparency and vitreous qualities. The examination of these particular specimens does not appear to have been carried sufficiently far to determine the fact; but it is by no means unlikely that the varying effect here noticed may have been owing to some difference in their original composition.

The greater the number of suitable ingredients that are employed in the composition of glass, the more easily and promptly does it become devitrified. This circumstance will sufficiently account for the fact of bottle-glass being the most suitable of any for conversion into Reaumur's porcelain. Having been compounded without much attention to the purity of its ingredients, this substance contains a great variety of earthy salts in minute quantities; while plate glass, which is a much more simple body, and in the manufacture of which the purified ingredients are brought together in the precise proportions that are required exactly to saturate each other, can be devitrified only partially, and with great difficulty.

On the other hand, in the same manner as a solution compounded of a great variety of saline bodies forms its crystalline deposits in a confused manner, so is it also observed that the fewer the number of ingredients which are contained in devitrified glass, the greater is the degree of regularity whereby its fibrous arrangement is attended; and for this reason plate glass, where the difficulty attending its devitrification has been overcome, furnishes, if not the most complete, yet certainly the most regular and beautiful specimens of Reaumur's porcelain.

It has been observed that glass, when devitrified, becomes a much more perfect conductor of heat and electricity than it was before it had changed its vitreous form. In fact, several pieces of glass, when converted into Reaumur's porcelain, could not be made to exhibit any sign of electricity by friction. This circumstance is rendered yet more remarkable by the fact, that glass which, having been once devitrified, has been made to resume its vitreous form by fusion, although it is thereby reinvested with its original density, fracture, and other characteristics, yet shows no greater disposition to become electric than it exhibited during its state of devitrification.

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